ALGORITHMS FOR INTEGRATED FEATURE RECOGNITION, MACHINABILITY CHECK AND NC PART PROGRAM GENERATION

by

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ALGORITHMS FOR INTEGRATED FEATURE RECOGNITION, MACHINABILITY CHECK AND N C PART PROGRAM GENERATION

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C E R T I F I C A T E

It is certified that the work contained in the thesis entitled *"Algorithms for Integrated feature Recognition, Machinability Check and N C part Program Generation"* by Mr. Rakesh Kumar Verma has been carried out under my supervision and that this work has not been submitted else where for a degree.

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ABSTRACT

Algorithms for feature recognition, checking th machinability and generating n c part programme for 2.5- prismatic parts have been developed in the present work. Th algorithms have been developed using boundary representation o the geometry of 2.5-D prismatic parts. The algorithms include th selection of tools.

The methodology developed has been implemented in Pasca language in Unix environment. Illustrative examples for th algorithms are presented in the thesis.

CHAPTER I

INTRODUCTION

Process planning is generally defined as the function within a manufacturing facility that specifies the process and information required to manufacture a part or assembly. Process plan in the machining environment may specify.

Type of operation to be performed.

Sequence of operations.

Machine selection.

Tools and Technological data.

Calculation of machining times and costs.

Raw materials required.

In the information flow chain, Process planning can be located between the design and the manufacturing function. So in principle PP is an information transforming activity. Input is an engineering part drawing and output is the process plan that prescribes the manufacturing method. The input of data from the drawing into the process planning function is performed using a human interface. Process planners should have a thorough knowledge of their machining facilities and of the ways in which production is usually performed in their organization. The experience of the process planners forms the major tool for transferring the drawing information into manufacturing specifications. The logic used are generally heuristic and involves problem solving in the absence of precise methods for example mathematical or algorithmic.

1.1 DEVELOPMENT OF COMPUTER AIDED PROCESS PLANNING

The use of computer resources to aid the process planner in a systematic determination of proper methods to be used in the production process is called CAPP. These systems manage the storage, retrieval, distribution and maintenance of the process plan library. They have extended to include the logic used by process planners in choosing alternate process methods. A key to the development of CAPP is to structure the data concerning parts fabrication, facilities, tooling and materials into categories and logical relationships.

Modern CAPP systems are focused around two technologies: variant and generative. The major difference between the two is the manner in which the manufacturing knowledge is stored.

1.1.1 VARIANT SYSTEMS

In this case the retrieval of relevant technological experience requires corresponding identification. Generally the part geometry and some technological aspects form a possible key for adequate retrieval.

The part geometry and some technological aspects of the part are described in the form of code numbers. The code numbers consist of a sequence of numerical digits each describing a certain aspect of the part For instance main shape, shape elements, dimensions, tolerance class e.t.c. The code number gives a general description of a part in such a way that similar parts have the same code numbers. When a new part is designed, the code numbers can be generated using a set of definitions and

connections.

Using the newly generated code numbers the computer can easily check which parts have the same (or nearly the same) code number. The process plan for similar parts is retrieved and suitably modified to get the process plan for the new part.

Successful application of the variant process planning system depends on the variety of the subject parts spectrum and the possibilities for adapting the part design to the set standards. Examples of variant system planning are

CAPP 3.1 (CAM-I Arlington, USA)

AUTAP (WZL Aachel, BRD)

CAPSY (IWF Berlin, BRD)

1.1.2 GENERATIVE SYSTEMS

Generative process planning systems should be able to generate process plans based on the information provided by the part drawings and relevant engineering specifications and information regarding manufacturing resources available. Contrary to the variant process planning systems which tends to standardize by making variants as close as possible to the original, the generative system in extreme produces a plan which is completely adaptive to the subject part.

LEVELS OF PROCESS PLANNING

Looking to the type of process planning systems which can be made generative we distinguish between two levels.

(1) Systems determining the manufacturing (N. C.) program on the one machine.

machines and other operations such as heat treatments, inspections e.t.c.

Systems of the first category are in fact intelligent NC-program generators. The problems they solve are of a few orders less complex than those of the systems of the second type. Basically they have to deal with one machine, a known set of tools, and geometrical features which are limited by the possibility of one machine.

Before the use of artificial intelligence in expert systems was generally recognized as a possibility of generative process planning, some systems were developed building on the work already done with variant system. One example is Genplan [1] developed by Lockhead, Georgia, U. S. A. Lockhead utilized a special coding and classification system to describe the attributes of parts. By using the experience laid down in some 100 process plans, it was possible to set up a data base of decision rules regarding the manufacturing of parts. The process plan for the new parts were prepared based on the decision rules mentioned above. Another example is Auto plan [2] developed by MetCut, U. S. A. Part of the system still utilizes group technology retrieval of historical information. However, interactive build up of new coding and decision trees made it possible to store process planning experience of a company specific nature.

The next step in process planning system development was the use of logic rules to determine the manufacturing details. The use of experts systems using artificial intelligence comes under this category. Expert systems basically contain a knowledge base in which rules and knowledge used by experts in the relevant field is stored and an 'inference engine' manipulating the rules in the

knowledge base in such a way that solutions can be generated to various problems. One of the early process planning systems making use of artificial intelligence is GARI [3]. It is a system that is able to plan prismatic parts which has to be milled or drilled.

In the same period a process planning system TOM [4] was developed. It showed the possibility to generate optimal machining sequence for a given hole geometry.

Even though most of the CAPP systems sold today are variant, current market trends are beginning to focus on generative systems. There are some major advantages of taking the generative approach: consistent plans, planner independence, the use and retention of the optimum manufacturing logic, compatibility with new technology,overall quality and vastly improved machine use. Also because this system does not rely on stored plans, it has unlimited flexibility and greatly diminished requirements for data storage.

1.2 FEATURE RECOGNITION SYSTEMS

A feature recognition system is responsible for transforming the part description obtained by a CAD system into machining features needed to drive a process planning system. The two dimensional boundary data is sufficient for the description of axisymmetric parts and prismatic parts with linear sweep. 3- D solids are represented either as the boundary representation (B-rep) or as the constructive solid geometry (CSG) binary tree.

There are mainly three methods of feature recognition which are discussed below.

(1) Volume decomposition method : In this method the volume to be removed is segmented into sub volumes that correspond to

machining operations. Each sub volume is associated with a machining feature.

(2) Searching for CSG patterns : Woo [6] proposed a method for extracting features from an object's CSG representation. An object's CSG representing is searched by the use of AI techniques to extract patterns, CSG fragments, that match with the feature definitions.

Lee and Fu [9] use tree manipulation techniques to rearrange an object's CSG representation so as to group certain CSG patterns that correspond to solid features.

(3) Searching for face patterns : A more promising approach is defining features as a set of faces that satisfy certain geometric relationships. The search is alone over boundary representation of the part.

Henderson and Anderson [10] developed procedures for searching the part description, recognizing the cavity volume, extracting features from cavity volumes and arranging them in feature graph (AAG) for the recognition of machined features from a 3- D boundary representation. Then graph based heuristics are applied on AAG to extract features.

1.3 AUTOMATED PROCESS PLANNING PROBLEMS

Automated process planning in its ideal form should function as follows. The engineering drawing and specifications of parts to be planned are available in a database having been drawn using a CAD-CAM system. Input of the part number and how many are to be manufactured should be sufficient to prompt the system to generate the process plan. The format in which the plan is generated, is such that it can be fed into the production control system since

route sheets generated by process planning forms input to scheduling and the integration of process planning and scheduling is essential [8]. Therefore in an ideal case no human interface is required.

But in reality, as long as a part can be manufactured using one machine only and then preferably using one set up, it seems possible to generate a process plan based on the part features. For instance X- Plane developed at the university of Twente is a process planning also capable of generating NC programs [7].

Moreover as soon as we have to plan a part that requires operations on different machines and also requires for instance heat treatment, cleaning and inspection at specific points, it is highly questionable if automated process planning can be realized within a reasonable time span with present possibilities.

Not only that, the quantity and complexity of rules is too large to handle for our present computers. A more serious problem is that the rules and decision process planners are using, seem impossible to be generalized. We may have to study the way a human is planning before we can truly start automation of process planning. Moreover the development of computer hardware and software should provide the means to handle this way of working, rapidly and in a user friendly way.

Summarizing areas for further research are :

CAD - CAM interface.

Knowledge base build up.

Interface to production control systems.

1.4 SCOPE OF THE PRESENT THESIS

The present thesis aims at developing a system which could recognize the feature, check the machinability and prepare a nc-part program for a 2.5D prismatic part. As discussed earlier these functions form an important components of process planning. The feature recognition algorithms are based on the volume decomposition approach. The system assumes that all the operations have to be performed on a single machine.

Although the plan generated by the system may not be the optimum one but it suggests one way in which the required part can be obtained by machining a stock of suitable size.

FEATURE RECOGNITION AND THEIR MACHINABILITY

The algorithm developed in the work is for 2.5D prismatic parts. 2.5D prismatic parts can be represented as a base plane and its extrusion. The base plane is a sequence of lines forming a closed figure and therefore can be called a polygon.

The geometric information about the part is fed in the form of a sequence of co-ordinates of the vertices of the polygon. The sequence is then scanned for various machining features. The list of the features recognized in the system and the conditions to be satisfied by them are discussed in the following section.

2.1 ALGORITHM USED FOR FEATURE RECOGNITION

(1) The set of coordinates of the vertices are fed to the system either through file or point by point, and is stored in the form of array of X and Y coordinate values. The input is given in the clockwise direction of the base plane.

(2) The base plane or the polygon is then searched for the pre-defined patterns of machinable features by scanning from start to end. When the instance of a feature is encountered, it is checked for machinability by checking two conditions - availability of tool and tool part interference. If the part is machinable, the feature is recognized and the co-ordinates of the

feature are stored. The feature is then separated from the polygon.

First the part is searched for complete features and then for partial features.

(3) If the feature is machinable, then tool code which is used for machining the feature is also stored along with the feature. If more than one tool is available, which can machine the given feature, then the one which requires minimum number of passes, is chosen.

(4) The position of the tool (i.e. the co-ordinates of the tool position) for each pass is stored along with the feature and tool code. These co-ordinates are then used for generating the n c part program for machining the part.

(5) The steps 2, 3 and 4 are coded with respect to the top side. Once the recognition of features on the top is completed, the part (and hence the co-ordinates) is rotated by 90 deg. in clockwise direction about point (0,0). The steps 2,3 and 4 are then repeated for left side.

(6) Similarly when feature recognition is complete for left side, the part is rotated by 90 deg. clockwise to recognize feature at the bottom and then again rotated by 90 deg. to get features on right side.

(7) The part may contain some non-machinable features. These features would remain unrecognized till now. Even some machinable

features could remain unrecognized due to these non-machinable features. Therefore the remaining sequence of co-ordinates is then checked for non- machinable features.

The non-machinable features are defined as those partial t-slots, partial dovetails or partial reverse dovetails or vertical slots which cannot be machined with the given tools or for which tool part interference occurs. If a complete t-slot, dovetail or reverse dovetail is non-machinable, then it is recognized as partial left and right t-slot, partial left and right dovetail and partial reverse left and right dovetail respectively.

The part is first checked for non- machinable features from the top. If no such feature is found then it is turned 90 deg.clockwise to check for the left side. In this way it is checked for all the four sides. As soon as one such feature is found, the co-ordinate of the feature is stored and the remaining co-ordinates are scanned for other machinable features. Therefore steps 2 to 7 are repeated until all the machinable and non-machinable features are found.

(8) Partial features are then merged to form complete feature, if they satisfy certain conditions. The conditions are discussed in one of the following sections.

(9) The tool position and the tool code noted along with the feature, in the earlier steps are then used to generate n c part program.

2.2 Pattern of Various Features

The features considered in the system are following

(1) T - slot (Complete and Partial)

(2) Dovetail (Complete and Partial)

(3) Reverse dovetail (Complete and Partial)

(4) V - slot

(5) Vertical slot.

A feature of a type is encountered when the sequence of points satisfy certain conditions applicable to that particular type. Mr. B. V. Rao [5] has also analyzed the various conditions to be satisfied by different features. The present work is an extension of his M.Tech. thesis.

2.2.1 T-SLOT

An instance of a T - slot is shown in fig. 2.1. It is a sequence of six points. The six points in the figure are point 1, 2, 3, 4, 5 and 6. X and Y co-ordinates of six points have to satisfy the following conditions to form a T - slot.

Top side conditions :

$$Y[1] = Y[2] = Y[5] = Y[6]$$

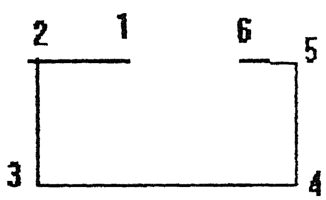
$$X[1] > X[2] \text{ and } X[5] > X[6].$$

Bottom side conditions :

$$Y[3] = Y[4] \text{ and } X[3] < X[4].$$

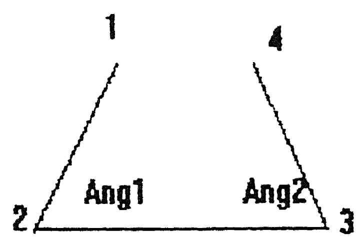
Left side conditions :

$$X[2] = X[3] \text{ and } Y[2] > Y[3].$$



A T-slot

FIG 2.1



A dovetail

FIG 2.2

Right side conditions :

$$X[4] = X[5] \text{ and } Y[5] > Y[4].$$

2.2.2 DOVETAIL

An instance of a dovetail is shown in the fig. 2.2. A dovetail is a sequence of 4 points. The four points in the figure are 1, 2, 3 and 4. X and Y co-ordinates of the points have to satisfy following condition to form a dovetail.

Top side :

$$Y[1] = Y[4].$$

Bottom side :

$$Y[2] = Y[3] \text{ and } X[2] < X[3].$$

Left side :

$$Y[1] > Y[2] \text{ and } X[1] > X[2].$$

Right side :

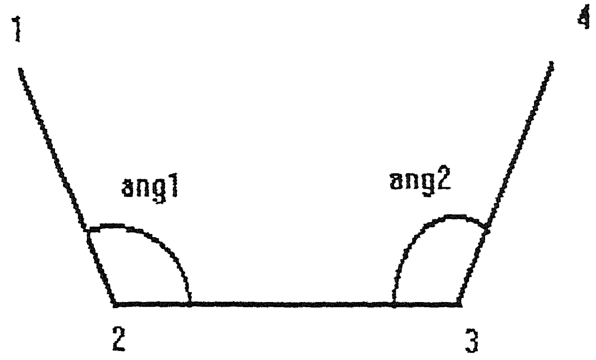
$$Y[3] < Y[4] \text{ and } X[3] > X[4].$$

One additional condition also has to be satisfied which ensures that Ang 1 and Ang 2 shown in fig. 2.2 are same. The condition is the following :

$$X[1] - X[2] = X[3] - X[4].$$

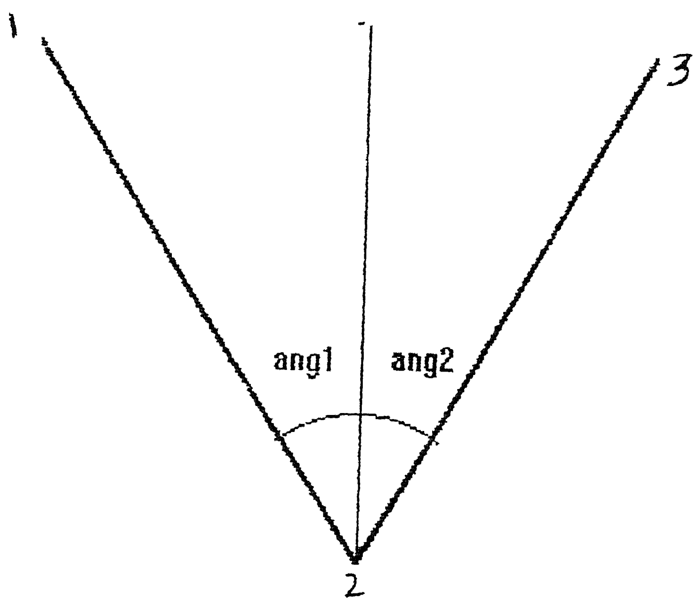
2.2.3 REVERSE DOVETAIL

An instance of the reverse dovetail is shown in fig. 2.3. A reverse dovetail is a sequence of four points. The four points in the figure are 1, 2, 3 and 4.



An example of reverse dovetail

FIG 2.3



An example of a V-SLOT

FIG 2.4

X and Y co-ordinates of the points have to satisfy the following conditions to be recognized as a reverse dovetail.

Top side :

$$Y[1] = Y[4].$$

Bottom side :

$$Y[2] = Y[3] \text{ and } X[2] < X[3].$$

Left side :

$$Y[1] > Y[2] \text{ and } X[1] < X[2].$$

Right side :

$$Y[3] < Y[4] \text{ and } X[3] < X[4].$$

One additional condition also has to be satisfied to ensure that Ang 1 and Ang 2 shown in fig. 2.3 are same. The condition is the following :

$$X[2] - X[1] = X[4] - X[3].$$

2.2.4 V-SLOT

An instance of V - slot is shown in fig. 2.4. A V-slot is a sequence of three points. The three points in the figure are points 1, 2, and 3. X and Y co-ordinates of the points have to satisfy following conditions to form a V-slot.

Top side :

$$Y[1] = Y[3].$$

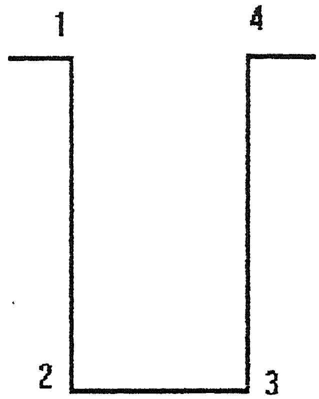
Left side :

$$Y[1] > Y[2] \text{ and } X[1] < X[2].$$

Right side :

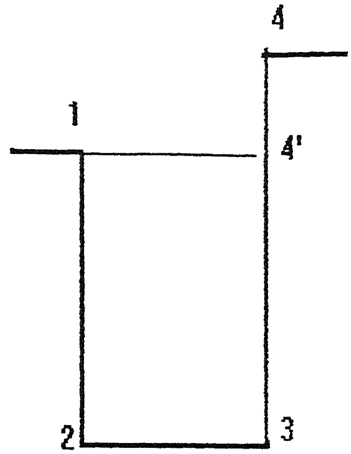
$$Y[2] < Y[3] \text{ and } X[2] < X[3].$$

One additional condition also has to be satisfied to ensure that Ang 1 and Ang 2 shown in fig. 2.4 are same. The condition is



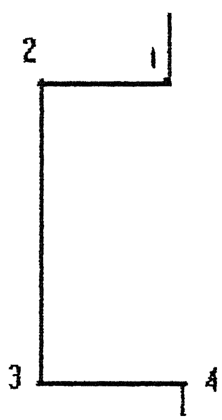
an example of a vertical slot

FIG 2.5 a



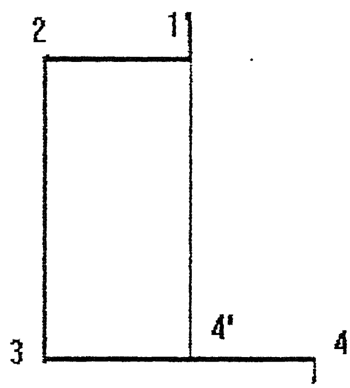
An example of a vertical slot
when the vertical sides are
not equal

FIG 2.5 b



An example of a partial
left T-SLOT

FIG 2.6 a



An example of left partial T-SLOT
when horizontal sides are not equal

FIG 2.6 b

the following :

$$X[2] - X[1] = X[3] - X[2].$$

2.2.5 VERTICAL SLOT

An instance of a Vertical slot is shown in fig. 2.5a. A Vertical slot is a sequence of four points 1, 2, 3 and 4. X and Y co- ordinates of the points have to satisfy the following conditions to form a Vertical slot.

Top side :

$$Y[1] = Y[4].$$

Bottom side :

$$Y[2] = Y[3] \text{ and } X[2] < X[3].$$

Left side :

$$Y[1] > Y[2] \text{ and } X[1] = X[2].$$

Right side :

$$Y[3] < Y[4] \text{ and } X[3] = X[4].$$

If Y[1] and Y[4] are not equal then a horizontal line is drawn through the minimum of the two as shown in fig. 2.5b. The enclosed figure formed by points 1, 2, 3 and 4 then form the V - slot.

2.2.6 PARTIAL T- SLOT LEFT

Fig. 2.6a shows a partial t- slot left. It a sequence of four points satisfying the following conditions.

Top side :

$$Y[1] = Y[2] \text{ and } X[1] > X[2].$$

Bottom side :

$$Y[3] = Y[4] \text{ and } X[3] < X[4].$$

Left side :

$$Y[2] > Y[3] \text{ and } X[2] = X[3].$$

If $X[1]$ and $X[4]$ are not equal then a vertical line is drawn through minimum of these two as shown in fig. 2.6b. The points 1, 2, 3, and 4 then form left partial t- slot.

2.2.7 PARTIAL T- SLOT RIGHT

A partial t- slot right is a sequence of 4 points as shown in fig. 2.7a. It satisfies the following conditions

Top side :

$$Y[3] = Y[4] \text{ and } X[3] > X[4].$$

Bottom side :

$$Y[1] = Y[2] \text{ and } X[1] < X[2].$$

Right side :

$$Y[2] < Y[3] \text{ and } X[3] > X[4].$$

If $X[1]$ and $X[4]$ are not equal then a vertical line is drawn through maximum of these two as shown in fig. 2.7b. The points 1, 2, 3 and 4 then form right partial T-slot.

2.2.8 PARTIAL DOVETAIL LEFT

A partial dovetail left is a sequence of two points satisfying the following conditions :

$$X[1] > X[2] \text{ and } Y[1] > Y[2]$$

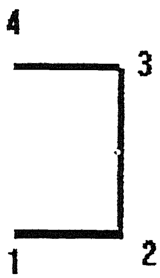
A vertical line is drawn through point 1 and a horizontal line is drawn through point 2. The intersection of these two lines give the third point '3' as shown in fig. 2.8. Points 1, 2, and 3 then form a partial dovetail left.

2.2.9 PARTIAL DOVETAIL RIGHT

A partial dovetail right is a sequence of two points satisfying the following conditions

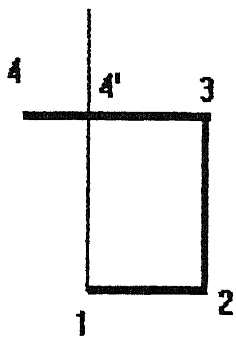
$$X[1] > X[2] \text{ and } Y[1] < Y[2]$$

A horizontal line is drawn through point 1 and a vertical



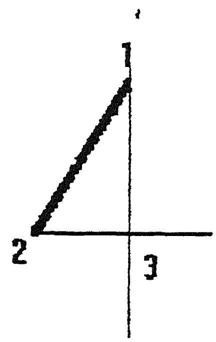
A partial right
T-slot

FIG 2.7 a



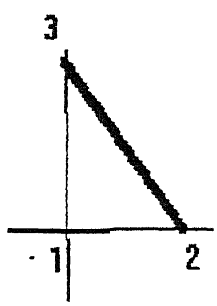
A partial right
T-slot when horizontal
sides are not equal

FIG 2.7 b



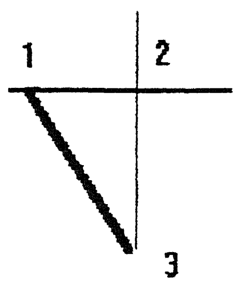
A partial left dovetail

FIG 2.8

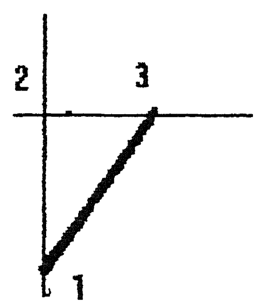


A partial right dovetail

FIG 2.9



A partial left reverse
dovetail
FIG 2.10



A partial right reverse
dovetail
FIG 2.11

line is drawn through point 2. The intersection of these two lines gives the third point '3' as shown in fig. 2.9. Points 1, 2, and 3 then form partial dovetail right.

2.2.10 PARTIAL REVERSE DOVETAIL LEFT

A partial reverse dovetail left is a sequence of two points satisfying the following conditions

$$X[1] < X[2] \text{ and } Y[1] > Y[2]$$

A horizontal line is drawn through point 1 and a vertical line is drawn through point 2. Intersection of these two lines forms the point 3. The points 1, 2, and 3 then form partial reverse dovetail left. An example of partial reverse dovetail left is shown in fig. 2.10.

2.2.11 PARTIAL REVERSE DOVETAIL RIGHT

A partial reverse dovetail right is a sequence of two points satisfying the following conditions

$$X[1] < X[2] \text{ and } Y[1] < Y[2]$$

A horizontal line is drawn through point 2 and a vertical line is drawn through point 1 as shown in fig. 2.11. Intersection of these two lines forms the point 3. The points 1, 2, and 3 then form partial reverse dovetail right.

2.3 CHECKING THE MACHINABILITY OF FEATURES

To check the machinability of each feature, a list of tools is maintained in the system. The types of cutting tool considered in the system are

(1) T - slot mill cutter

(2) Dovetail mill cutter

(3) Reverse dovetail mill cutter

(4) Equal angle mill cutter

(5) Single angle mill cutter.

T - slot mill cutters are used to machine complete and partial t-slots.

Dovetail mill cutters are used to machine partial and complete dovetails.

Reverse dovetail mill cutters are used to machine complete and partial dovetails.

Equal angle mill cutters are used to machine V- slots and partial reverse dovetails.

Single angle mill cutters are used to machine partial reverse dovetails.

2.4 CONDITIONS FOR MACHINABILITY OF FEATURES

As discussed earlier, a feature is machinable if -

1) A suitable cutter is available to machine the feature .
2) There is no tool part interference while machining.

2.4.1 ALGORITHM FOR CHECKING TOOL PART INTERFERENCE

1. The tool is positioned at the location where the tool part interference has to be checked. The co-ordinates of various corners of the tool are then calculated in the same co-ordinate system as that of the parts on the basis of its dimensions. The step is explained with the help of an example. A T- slot feature shown in fig. 2.12a has to be checked for tool part interference when the cutter is at the extreme left of the top portion of the feature. The position of the cutter is shown in fig 2.12c. The point 3 of the cutter coincides with point b of the T- slot feature. . The co-ordinates of points 1, 2, 3, 4, 5, 6, 7 & 8 of the cutter are then calculated depending on its dimensions.

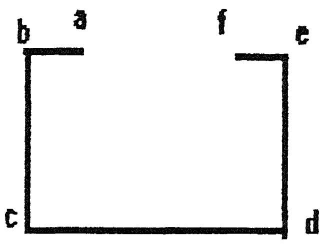


FIG 2.12 a

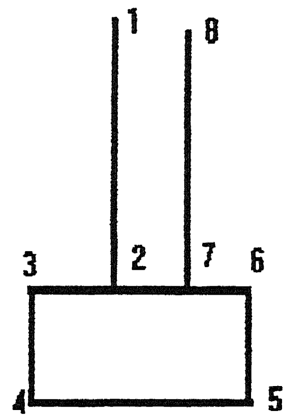


FIG 2.12 b

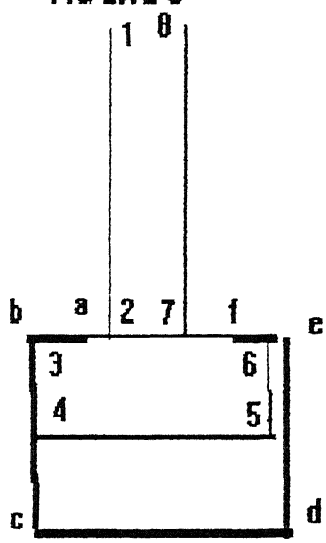


FIG 2.12 c

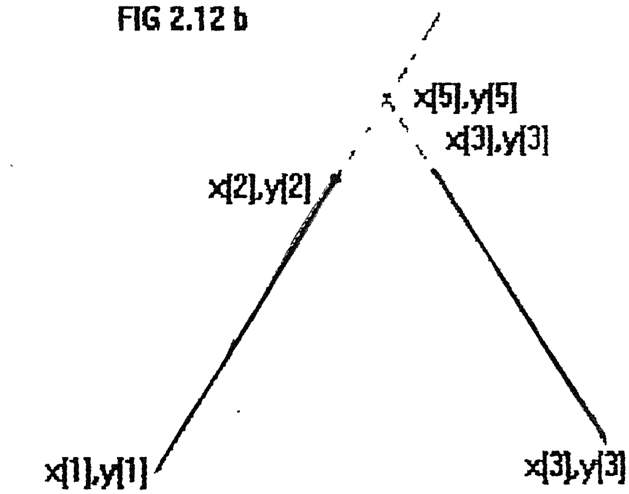


FIG 2.13

2. The equation of lines formed by two successive points of the polygon and that of the cutter are calculated. Each line of the polygon is checked with each line of cutter, for interference. It can be easily seen that there exists no interference between two lines if they satisfy any one of the following conditions.

a. Slope of two lines are equal i.e. they are parallel.

b. If two lines are not parallel, then the condition for which interference does not exist is explained by the following example (see fig 2.13 .). Line 1-2 and line 3-4 intersect at point 5. The values of X and Y co-ordinates of point 5 are calculated from the equations of two lines. The following conditions are to be satisfied for non interference of the lines.

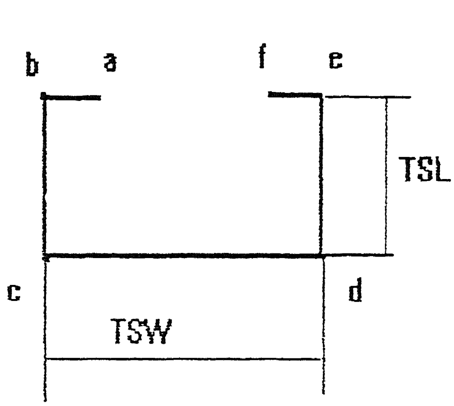
(X[5] ≤ X[1] and X[5] ≤ X[2])
OR (X[5] ≥ X[1] and X[5] ≥ X[2])
OR (Y[5] ≤ Y[1] and Y[5] ≤ Y[2])
OR (Y[5] ≥ Y[1] and Y[5] ≥ Y[2])
OR (X[5] ≤ X[3] and X[5] ≤ X[2])
OR (X[5] ≥ X[3] and X[5] ≥ X[4])
OR (Y[5] ≤ Y[3] and Y[5] ≤ Y[4])
OR (Y[5] ≥ Y[3] and Y[5] ≥ Y[4])

Interference does not exists between line & part if combination of each line of the polygon and each line of the cutter satisfy one of the above given conditions.

2.4.2 CHECKING MACHINABILITY OF A T-SLOT

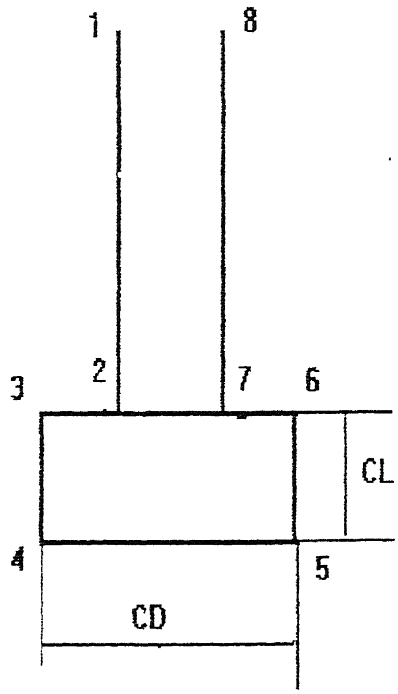
When an instance of T-slot is encountered, the list of T-slot cutters is scanned to find a suitable tool to machine the feature. Each T-slot cutter is checked for tool part interference. If more than one T-slot cutter are found to be suitable to machine the feature then one which requires minimum number of passes is selected. Calculation of number of passes is discussed in one of the later sections of the thesis.

Fig 2.14a and 2.14b show a T-slot and a T-slot cutter respectively. The terminology used in the discussion is explained in fig 2.14.The various conditions to be satisfied by different cases of machinable T-slots are discussed below.



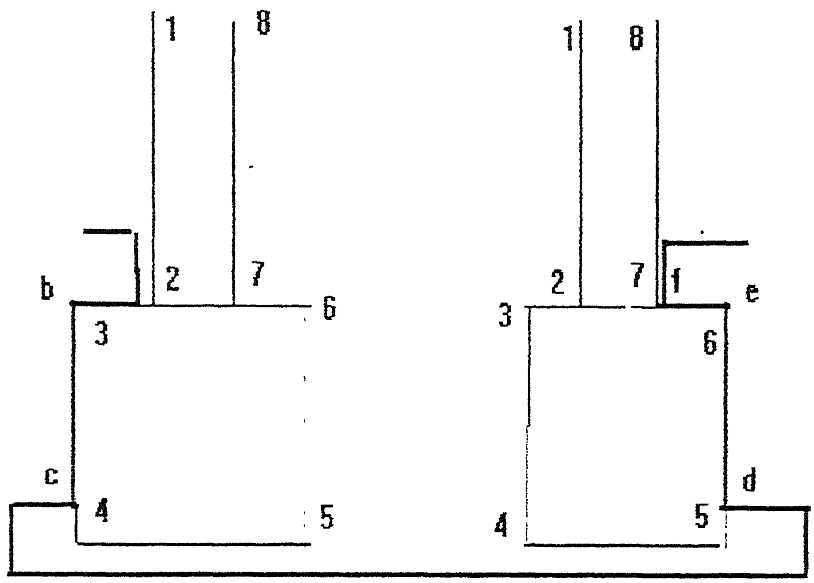
A T-slot

FIG 2.14 a



A T-slot cutter

FIG 2.14 b



points a, b, c, d, e and f form a T-slot

CL >= TSL and CD =< TSW

FIG 2.15 a

<u>case 1.</u> CL ≥ TSL and CD ≤ TSW

An instance of this case is shown in fig 2.15a. The cutter is checked for tool part interference at two extremes as shown. For checking left extreme the point b on feature is coincided with point 3 on the cutter and for checking extreme right point e on feature is coincided with point 6 on cutter. If tool part interference does not occur at these two points then the T-slot is machinable with given cutter.

To ensure that the tool reaches the total depth of the T-slot, the following condition is satisfied.

Assuming that Y is an array of Y co-ordinates of polygon, Y_{max} is the maximum value of Y co-ordinate and PY[1] is the co-ordinate of point 1 on the cutter then

$$Y_{max} \le PY[1].$$

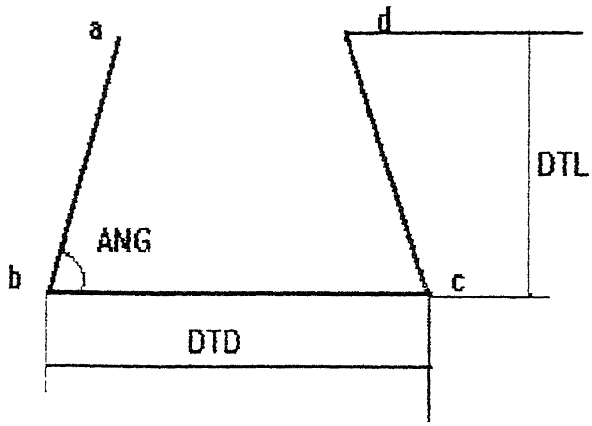
<u>Case 2.</u> CL < TSL and CD ≤ TSW

An instance of this case is shown in fig 2.15b. The cutter is checked for tool part interference first at lower left portion of the T-slot and then at lower left portion of the T-slot. In other words, first the point 4 of T-slot cutter is coincided with point c of the T-slot feature and then point 5 is made to coincide with point d of the T-slot feature. If tool part interference does not occur at these two points and $Y_{max} \le$ PY[1] then the T-slot cutter is chosen.

<u>2.4.3 CHECKING THE MACHINABILITY OF DOVETAIL</u>

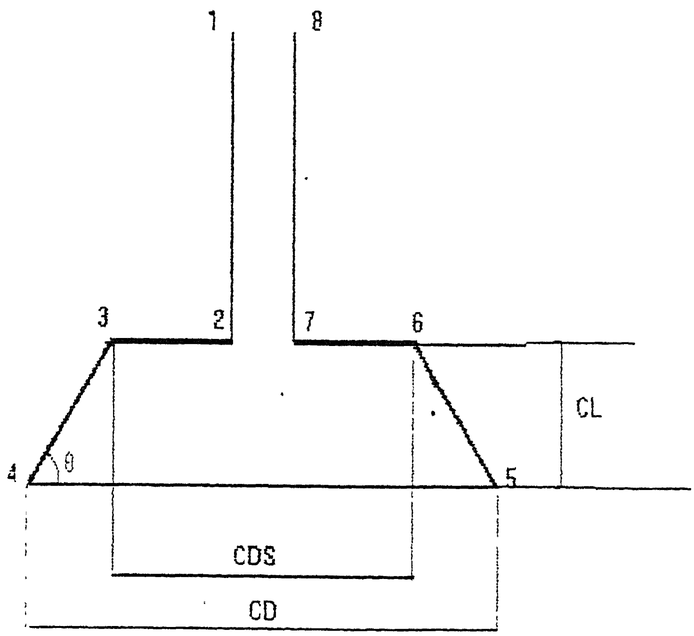
When an instance of dovetail is encountered then the list of dovetail cutters is scanned to find a suitable cutter to machine the feature. Each dovetail cutter is checked for angle and tool part interference. If more than one cutter are available then one with minimum number of passes is chosen.Fig 2.16a and fig 2.16b show a dovetail and a dovetail cutter respectively. The terminology used in the discussion is explained in fig 2.16.

The various conditions to be satisfied by different cases of machinable dovetails are discussed below.



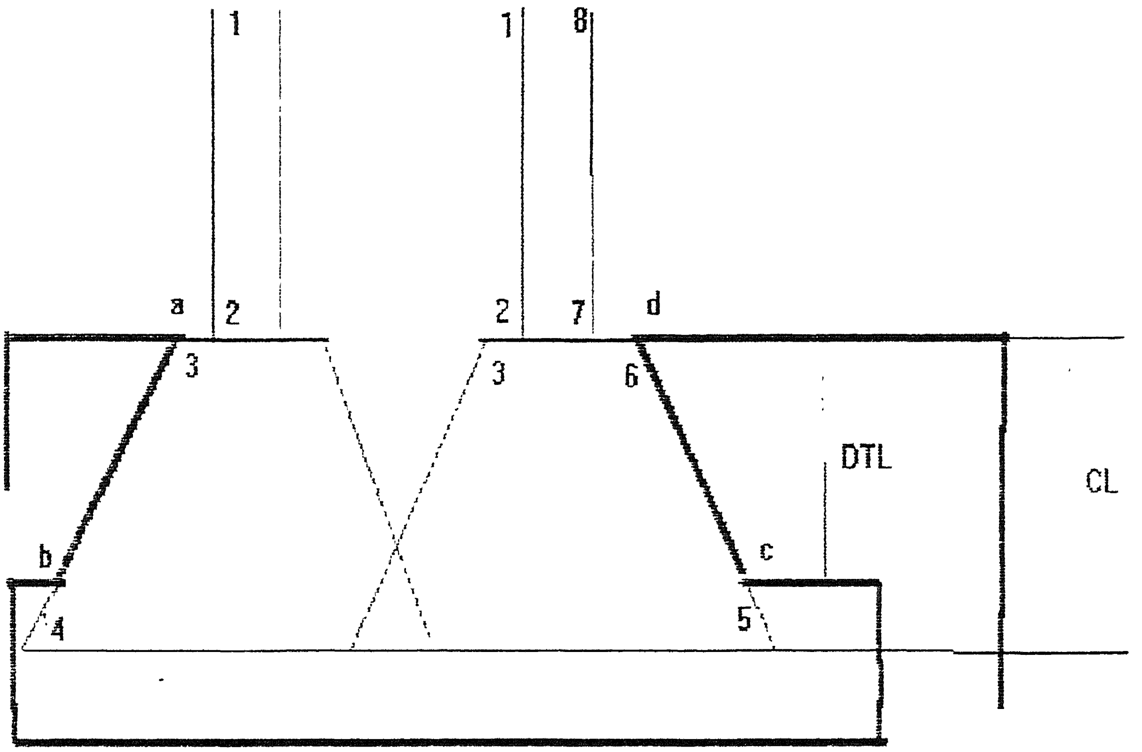
POINTS a, b, c & d form dovetail

FIG 2.16a



A dove tail Cutter

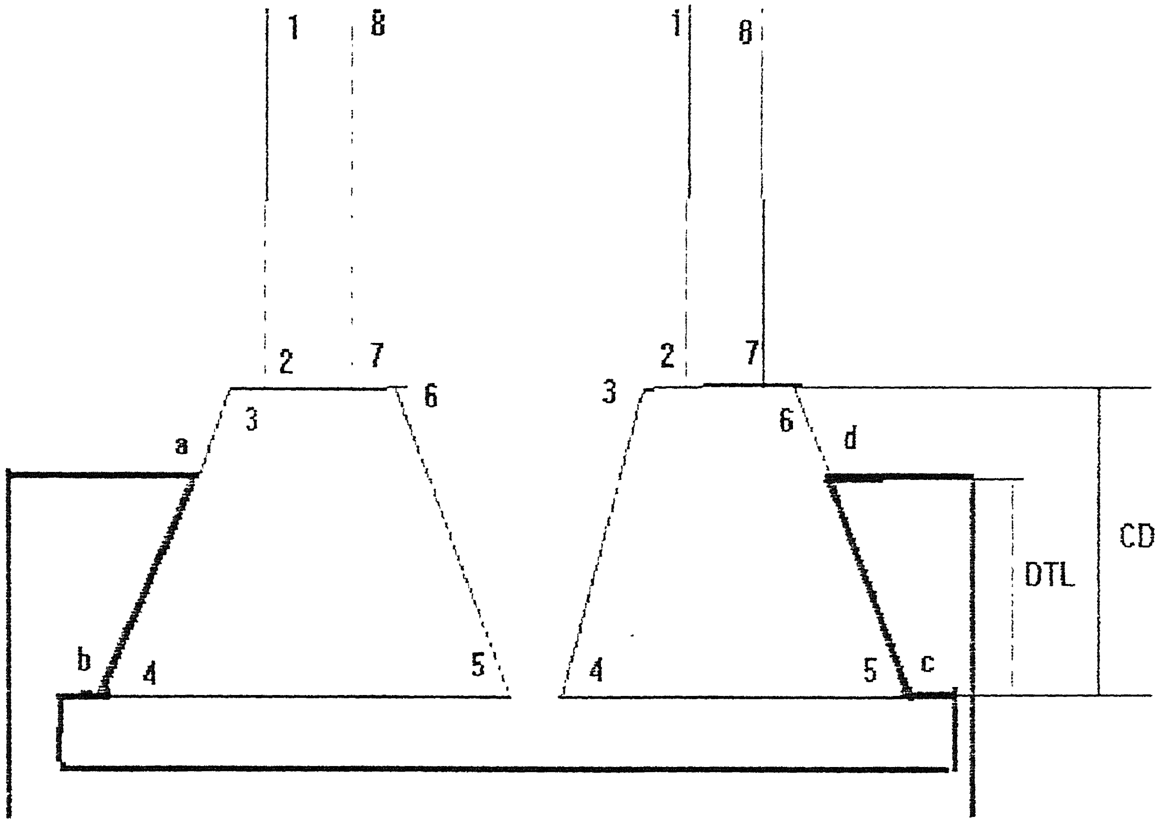
Fig 2.16b



a, b, c and d form a dovetail

Ang = θ and CL >= DTL

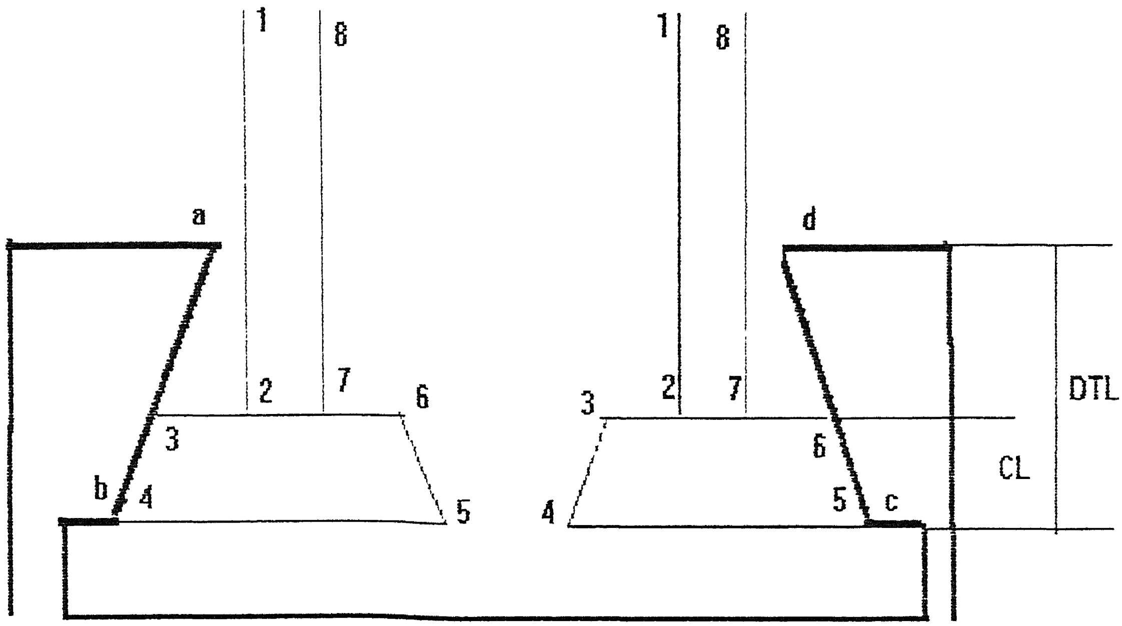
FIG 2.17a



a, b, c and d form a dovetail

Ang = θ and CI >= DTL .

FIG 2.17b



pointa a, b, c and d form a dovetail

Ang $= \theta$ and CL < DTL

FIG 2.17 c

Case 1 Ang = θ, CL $\geq$ DTL

An instance of this case is shown in fig 2.17a. The cutter is checked for tool part interference at two extremes as shown. For checking left extreme the point 3 of dovetail cutter is made to coincide with point a of the dovetail feature. For checking the right extreme the point 6 of dovetail cutter is made to coincide with point d of dovetail feature. If tool part interference does not occur then the cutter is chosen.

If tool part interference occurs then the same tool is located at the two extremes of the lower end of the dovetail as shown in fig 2.17b and checked for tool part interference. First point 4 of dovetail cutter is made to coincide with point b of dovetail and then point 5 of dovetail cutter is made to coincide with point c of the dovetail. If tool part interference does not occur then the tool is chosen and the position and code of the tool is noted.

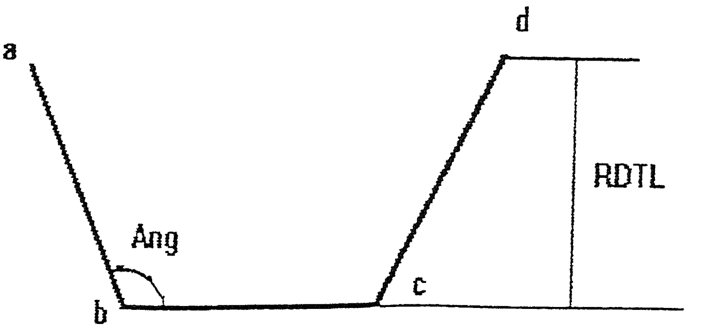
To see whether the tool can reach total depth of the dovetail the following condition should be satisfied.

Assuming that Y is an array of Y co-ordinates of polygon, Y_{max} is the maximum value of the Y coordinate of the polygon and PY[1] is the coordinate of point 1 on the cutter then

$$Y_{max} \leq PY[1]$$

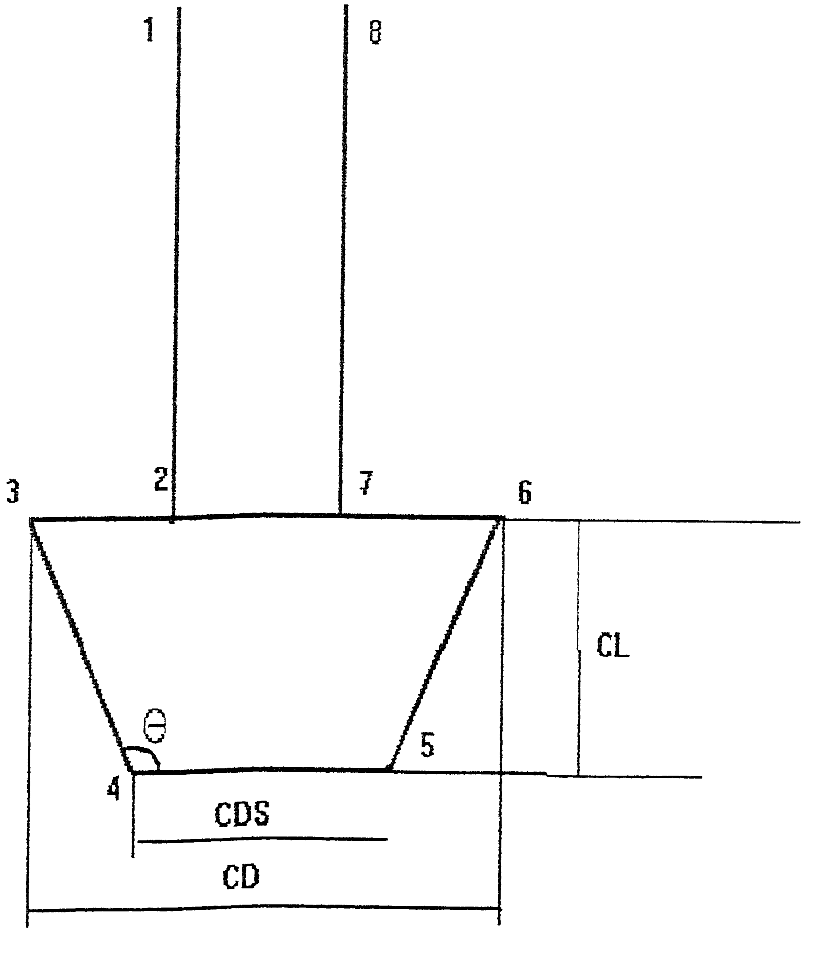
Case 2 Ang = θ, CL < DTL and CD < DTD

An instance of this case is shown in fig 2.17c. The cutter is checked for tool part interference at the two extreme points at the lower end of the dovetail. For checking the left extreme, point 4 of dovetail is made to coincide with point b of dovetail. For the right extreme, point 5 is coincided with point c of dovetail. If the tool part interference does not exist and the condition $Y_{max} \leq PY[i]$ is satisfied then the tool is selected. The tool position and tool number are noted.



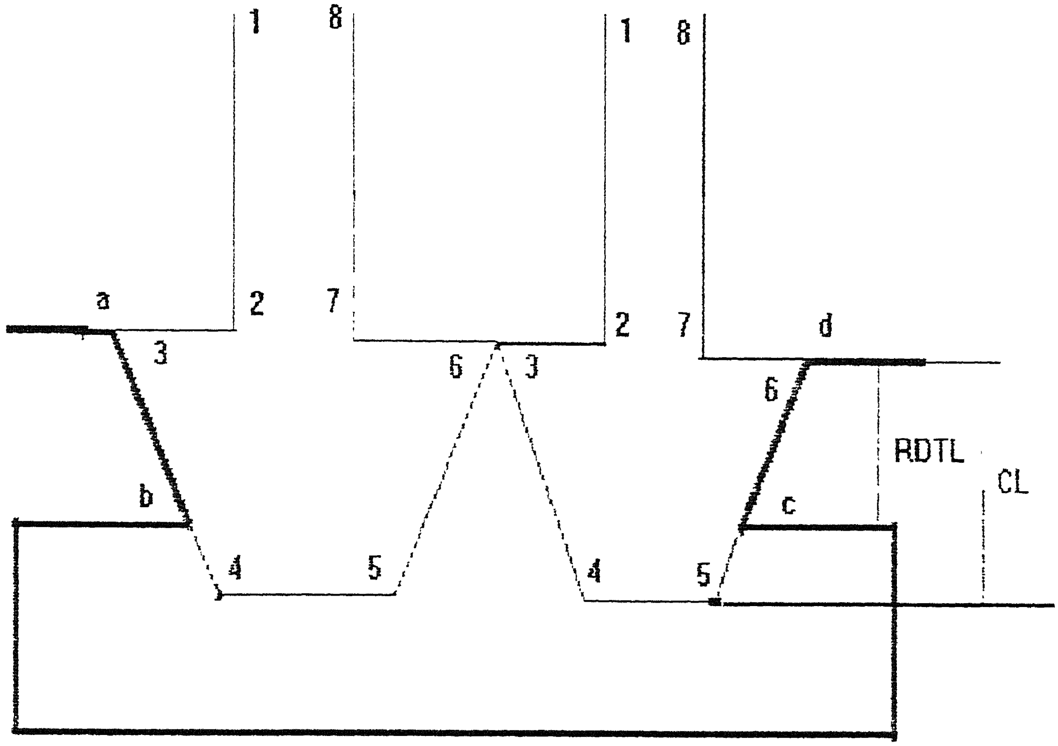
A Reverse Dovetail

FIG 2.18 a



A Reverse Dovetail Cutter

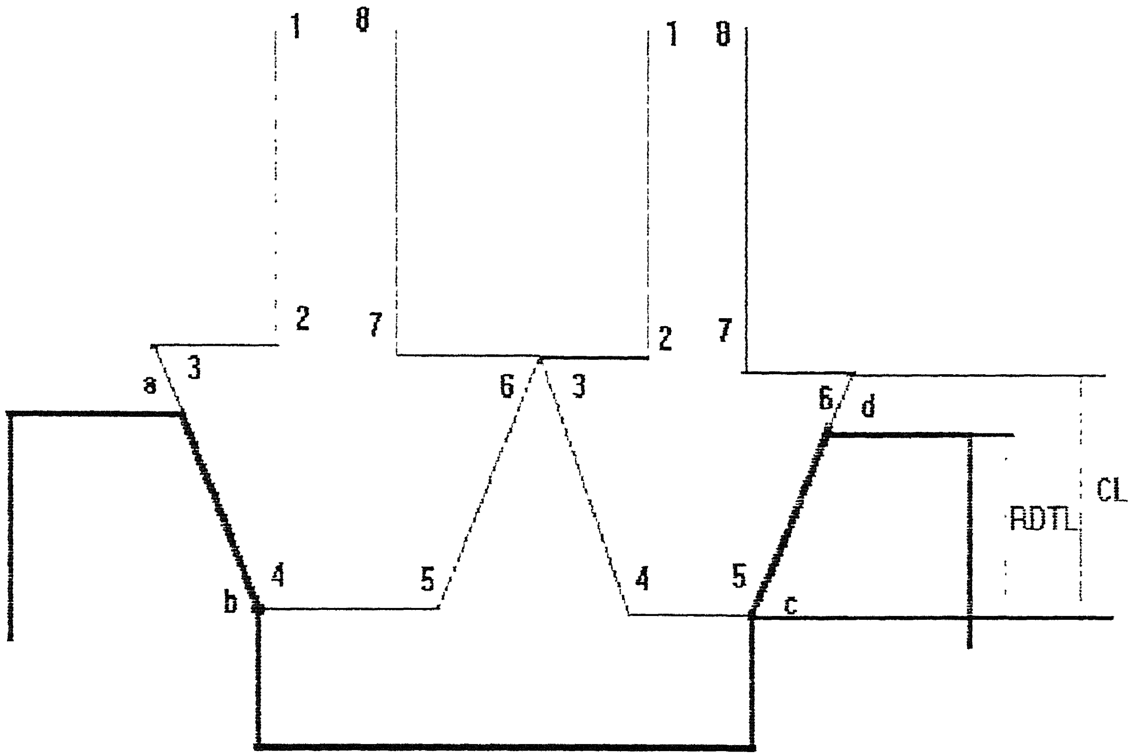
FIG 2.18 b



POINTS 1,2,3 & 4 form a reverse dovetail

$CL \geq RDTL$

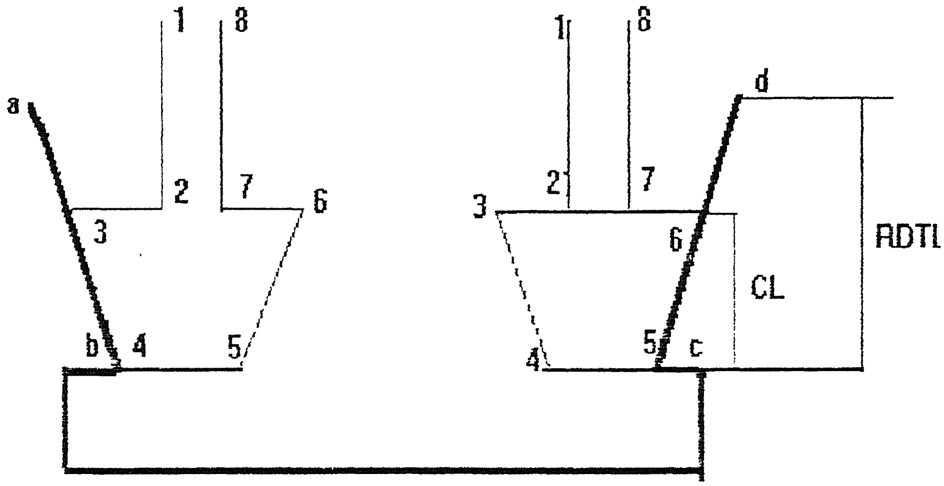
FIG 2.19a



POINTS 1,2,3 & 4 form a reverse dovetail

$CL \geq RDTL$

FIG 2.19b



POINTS a,b,c AND d FORM A REVERSE DOVETAIL

FIG 2.19C

2.4.4 CHECKING THE MACHINABILITY OF A REVERSE DOVETAIL

When instance of reverse dovetail is encountered then the list of reverse dovetail cutters is scanned to find a suitable tool to machine the feature. Each reverse dovetail cutter angle is matched with the feature angle and if they match then both are checked for tool part interference. If more than one cutter are found to be suitable then the the cutter which requires minimum number of passes is selected.

Fig 2.18a and fig 2.18b show a reverse dovetail and a reverse dovetail cutter respectively. The terminology used in the discussion is explained in the fig 2.18. the various conditions to be satisfied by the machinable reverse dovetail are given below.

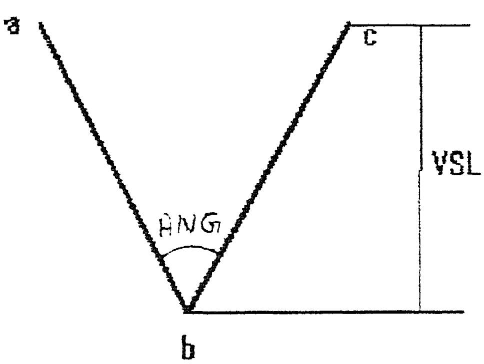
Case 1 $\quad$ Ang = θ, CL $\geq$ RDTL

An instance of this case is shown in fig 2.19a. The cutter is first checked for the part interference at the two extremes of the upper end of the feature. That is point a is coincided with the point 3 of the cutter and the point d is coincided with the point 6 of cutter. If tool part interference does not occur then the cutter is chosen.

If tool part interference exists at the above positions of the tool then the tool is placed at the lower ends of the dovetail as shown in fig 2.19b. That is point b is coincided with point 4 of the cutter and then the point c is coincided with the point 5 of cutter. If tool part interference does not occur here then the cutter is chosen.

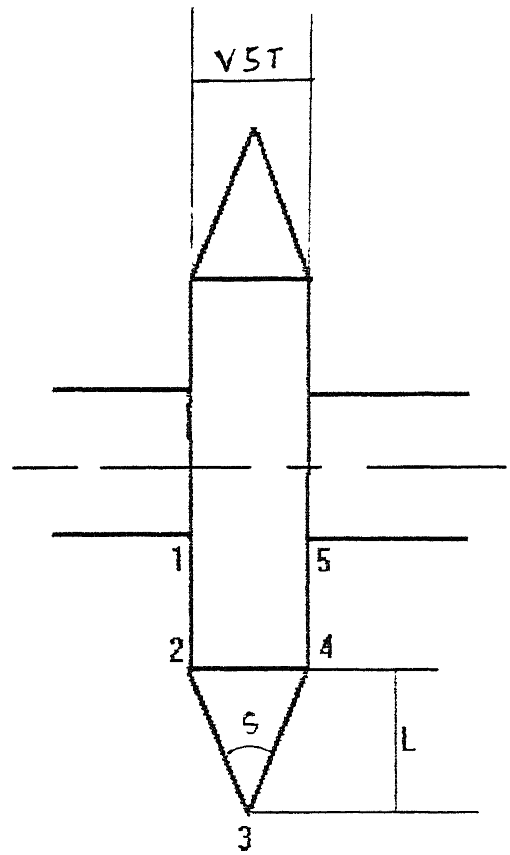
Case 2 $\quad$ Ang = θ, CL < RDTL

An instance of this case is shown in fig 2.19c. The cutter is checked for the tool part interference at two extremes of the lower end of the reverse dovetail. That is point b of reverse dovetail feature is coincided with point 4 of the cutter and point c of the reverse dovetail feature with point 5 of cutter. If tool



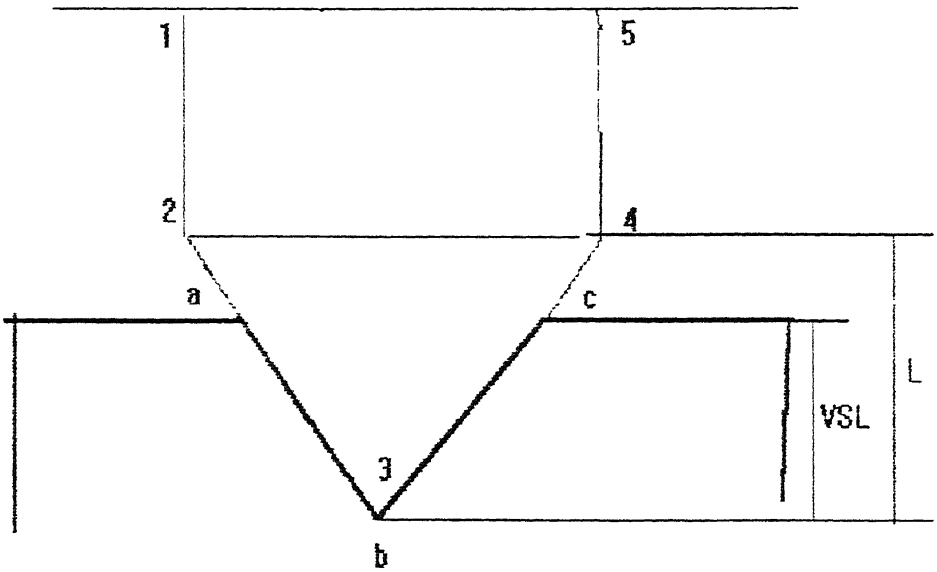
A V-slot

FIG 2.20 a



A V-slot cutter

FIG 2.20 b



point a, b, c form a V-slot

FIG 2.20 c

part interference does not exists then the cutter is chosen.

For the above two cases, $Y_{max} \leq PY[1]$ has to be satisfied for the feature to be machinable. Here Y_{max} is maximum value of Y co-ordinate of all the points in the polygon and PY[1] is the value of Y coordinate of point 1 on reverse dovetail cutter.

2.4.5 CHECKING THE MACHINABILITY OF A V-SLOT

When an instance of a V-slot is encountered then the list of V-slot cutters is scanned to find a suitable tool to machine the feature. The angle of V-slot cutter and V-slot are first matched. If they are equal, then the tool is checked for tool part interference. Fig 2.20a and fig 2.20b show a V-slot and a V-slot cutter respectively.

The condition to be satisfied by the V-slot cutter is

$$Ang = \theta \text{ and } L \geq VSL \text{ and } Y_{max} \leq PY[1],$$

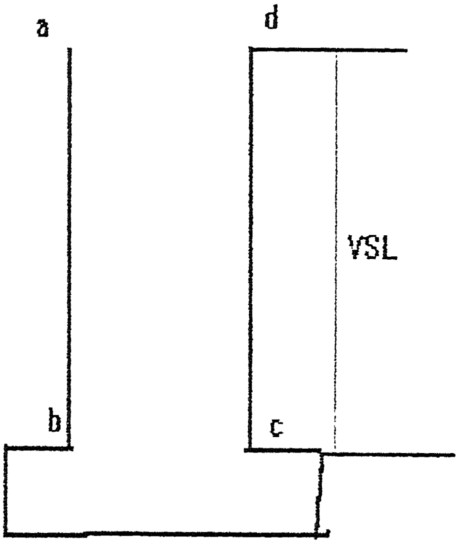
where PY[1] is the value of Y coordinate of point 1 in fig 2.20b. An instance of this case is shown in fig 2.20c.

2.4.6 CHECKING THE MACHINABILITY OF VERTICAL SLOT

When an instance of a vertical slot is encountered then the list of T-slot cutters and End mill cutters is scanned to find a suitable tool. Each T-slot cutter and End mill cutter is checked for tool part interference.

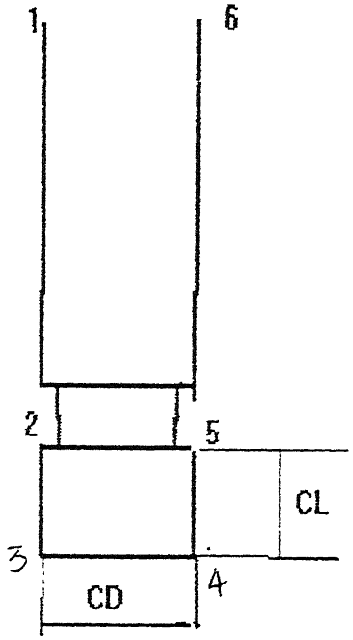
If more than one cutter are found to be suitable then the one requiring minimum number of passes is selected. Calculation of number of passes is discussed in one of the following sections.

Fig 2.21a and fig 2.21b show a vertical slot and End mill cutter respectively. The terminology used in the discussion is explained in the fig 2.21. Checking the machinability with a T-slot cutter is exactly similar as that with end mill cutter.



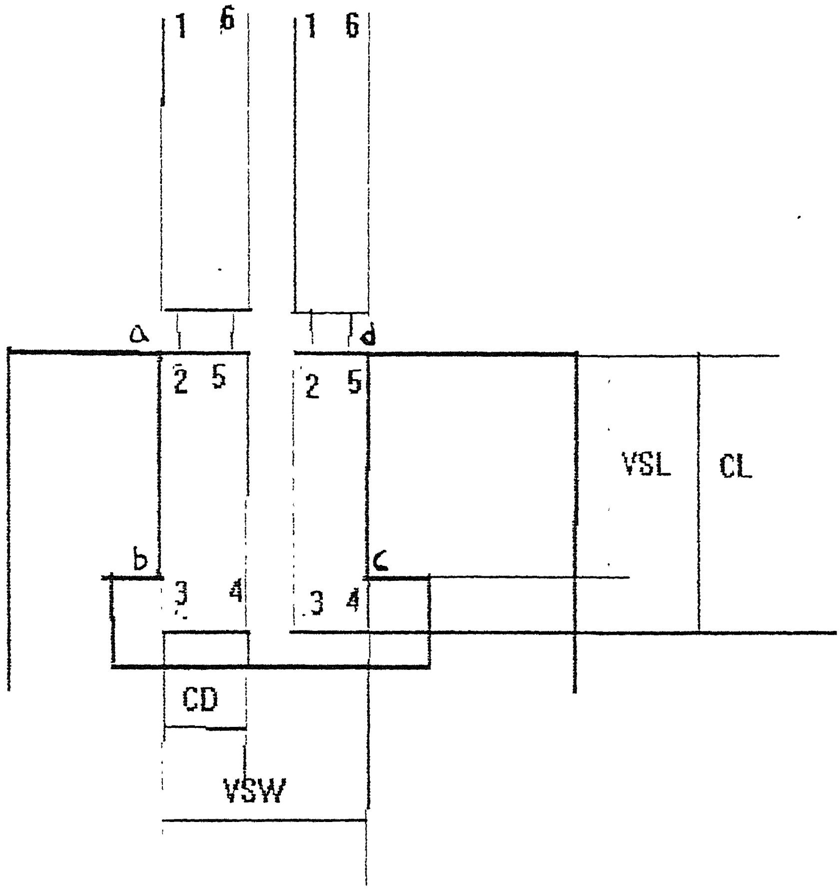
points a, b, c and d form a
vertical slot

FIG 2.21 a



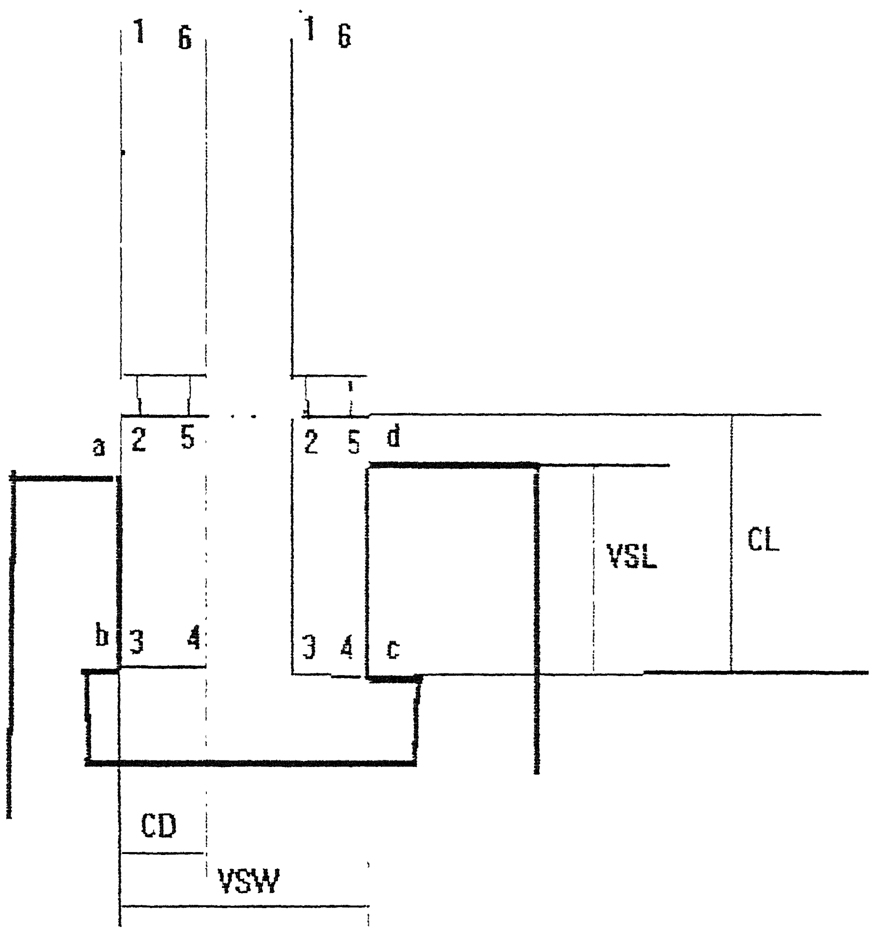
AN END MILL CUTTER

FIG 2.21 b



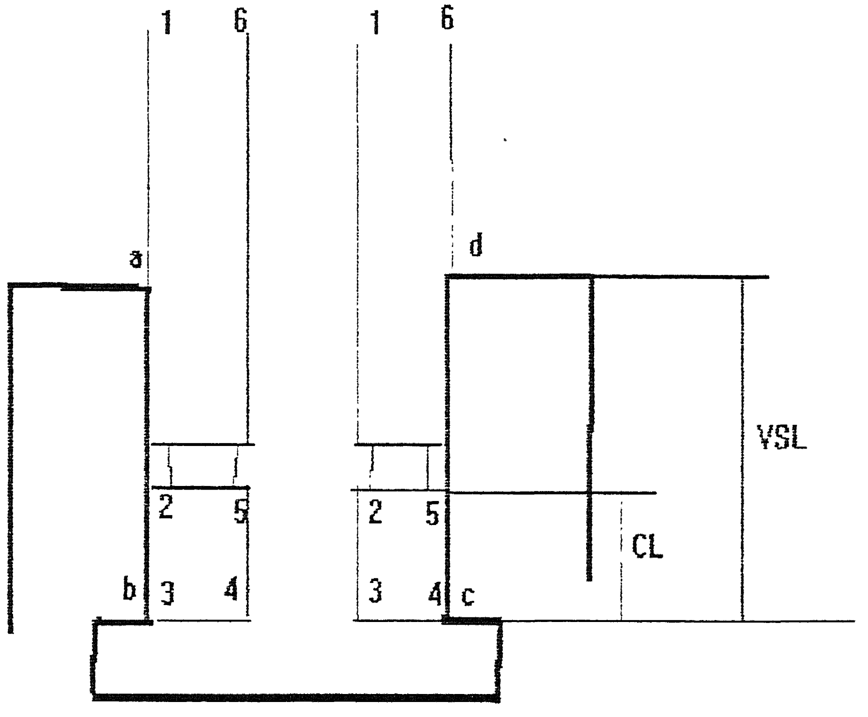
points a, b, c and d form a vertical slot

FIG 2.22 a



points a, b, c and d form a vertical slot

FIG 2.22 b



points a, b, ,c and d form a vertical slot

FIG 2.22 c

Case 1 CL ≥ VSL and CD ≤ VSW

The instance of this case is shown in fig 2.22a. The tool is placed at the two extremes of the upper end of the vertical slot that is point a is coincided with point 2 of cutter (point 3, if it is a T-slot cutter) and then point d is coincided with point 5 of cutter (point 6 if it a T-slot cutter). If the tool part interference does not exist two positions then the tool is chosen.

If the tool part interference occurs at any one of the above two positions when the tool is placed at the two extremes of the lower end of the vertical slot as shown in fig 2.22b i.e point b is coincided with point 3 of the cutter (point 4 for T-slot cutter) and the point c is coincided with point 4 (point 5 for T-slot cutter). If tool part interference does not exist at the two locations then the tool is chosen.

Case 2 CL < VSL and CD < VSW

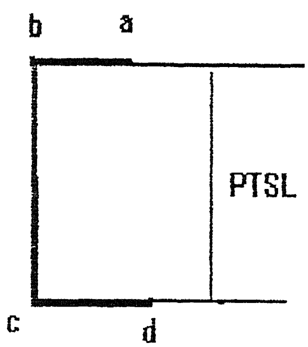
The instance of this case is shown in figure 2.22c. Tool is placed at the two extremes of the lower end of the vertical slot and checked for tool part interference i.e point b is coincided with point 3 of cutter (point 4 for T-slot cutter) and point c is coincided with point 4 of the cutter (point 5 for T-slot cutter). If interference does not occur then the tool is chosen for machining.

For the above two cases additional condition which has to be specified is $Y_{max} \leq PY[1]$ where PY[1] is value of Y coordinate of point 1 of the cutter.

2.4.7 CHECKING THE MACHINABILITY OF A PARTIAL LEFT T-SLOT

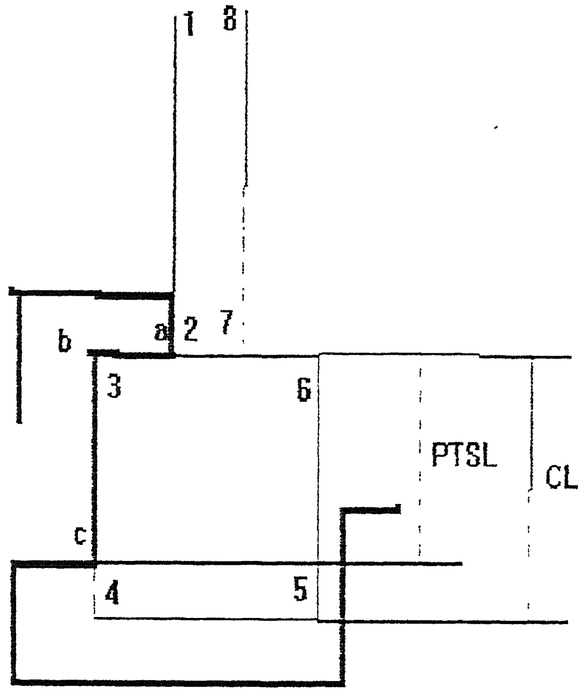
When an instance of partial left T-slot is encountered then the list of T-slot cutters is scanned to find a suitable tool. Each T-slot cutter is checked for tool part interference.

If more than one cutter is found to be suitable the the one requiring minimum number of passes is chosen. Calculation of the



A partial right T-slot

FIG 2.23 a



CL >= PTSL

FIG 2.23 b

number of passes is discussed in one of the following sections.

Fig 2.23a shows a partial left T-slot and the terminology used. The terminology used for T-slot cutter is same as explained in fig 2.14b.

The various conditions to be satisfied by different cases of partial left T-slot are given below

Case 1 $CL \geq PTSL$

An instance of the case is shown in fig 2.23b. The tool is placed at the top of the partial left T-slot i.e. point b is coincided with point 3 of the cutter and checked for tool part interference. If tool part interference does not exists then the tool is chosen.

Case 2 $CL < PTSL$

The tool is first located at the top portion of the partial left T-slot i.e point b is coincided with point 3 and then at the lower end i.e. point c is coincided with point 4 of the cutter. For the feature to be machinable, tool part interference should not exist at both the locations.

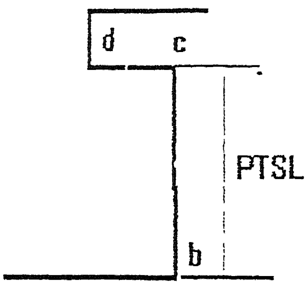
For the above two cases, additional conditions which has to be satisfied is $Y_{max} \leq PY[1]$.

2.4.8 CHECKING THE MACHINABILITY OF PARTIAL RIGHT T-SLOT

When an instance of partial right T-slot is encountered then the list of the T-slot cutters is scanned to find a suitable tool. Each T-slot cutter is checked for tool part interference.

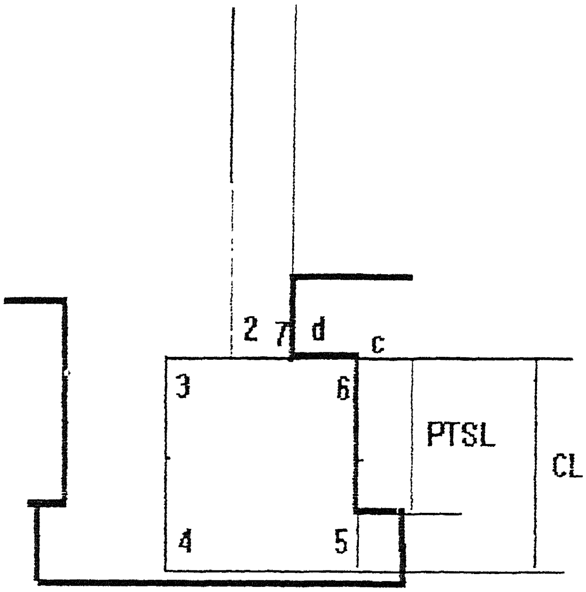
If more than one cutter are found to be suitable then the one requiring minimum number of passes is chosen. Calculation of number of passes is discussed in one of the following sections.

Fig 2.24a shows a partial right T-slot & the terminology used. The terminology used for T-slot cutter is same as that



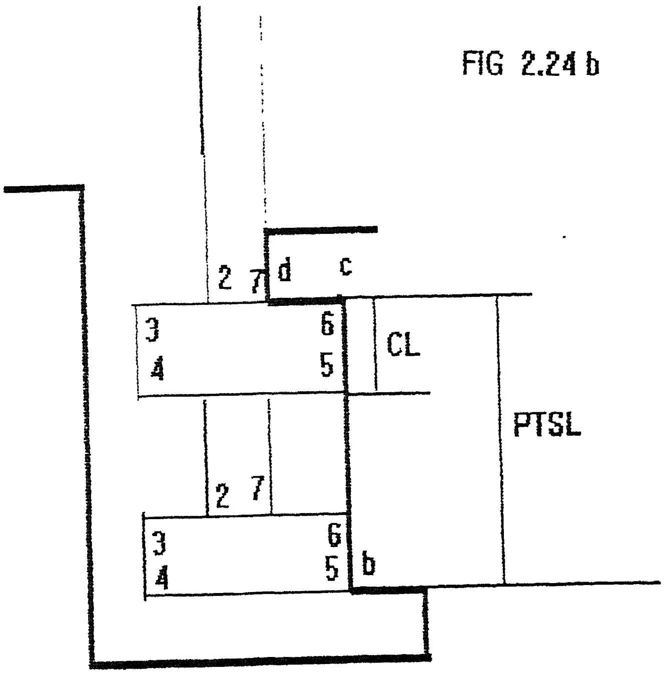
A partial right T-slot

FIG 2.24 a



CL >= PTSL

FIG 2.24 b



CL < PTSL

FIG 2.24 c

explained in fig. 2.14b.

The various conditions to be satisfied by different cases of machinable partial right T-slot are given below.

Case I $\qquad CL \geq PTSL$

An instance of the case is shown in fig 2.24b. The point 6 of tool is made to coincide with point c of the partial right T-slot & tool part interference is checked at that location. If no tool part interference exists then the tool is chosen.

Case II $\qquad CL < PTSL$

An instance of the case is shown in fig 2.24c. At first the cutter is located such that point 6 of the tool coincides with the point c of the partial right T-slot. Tool-part interference is checked at this location . Then the tool is shifted to the lower end of the feature such that point 5 of the cutter coincides with point b of the the partial right T-slot. Tool-part interference is again checked at this location . If the interference does not exist at both points, then the tool is chosen. For the above two cases , the additional condition to be satisfied is

$$Y_{max} \leq PY[1]$$

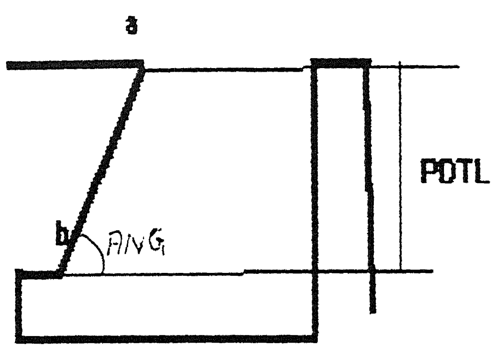
2.4.9 CHECKING THE MACHINABILITY OF A PARTIAL LEFT DOVETAIL

When an instance of a partial left dovetail is encountered then the list of dovetail cutters is scanned to find a suitable cutter. Each dovetail cutter is checked for tool part interference.

If more than one cutter are found to be suitable then the one requiring minimum number of passes is chosen. Calculation for minimum number of passes is discussed one of the following sections.

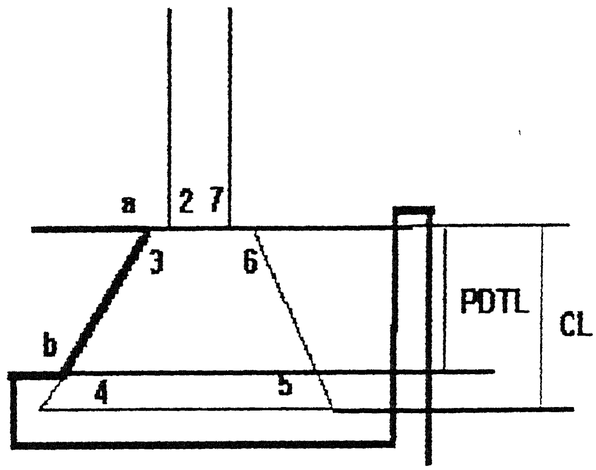
Fig 2.25a shows a partial left dovetail & the terminology used. The terminology used for a dovetail cutter is same as explained in fig 2.16b.

The various conditions to be satisfied by different cases of machinable partial left dovetail are given below.



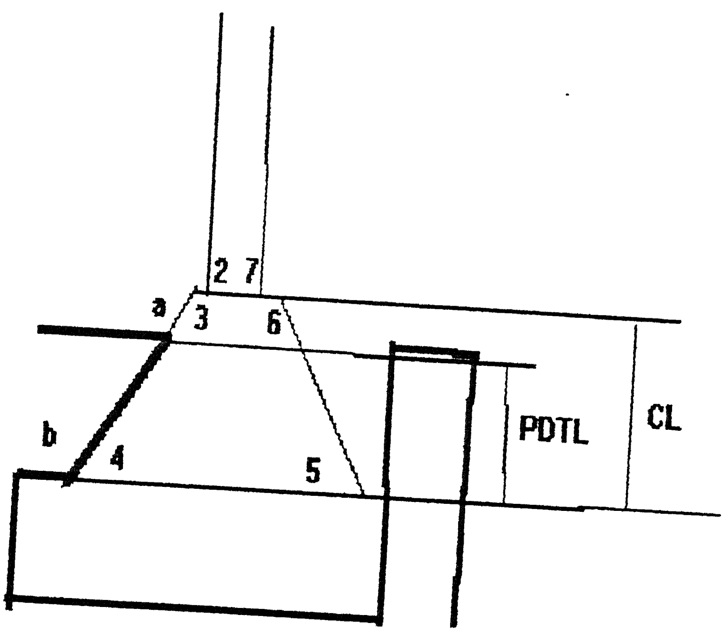
A partial left dovetail

FIG 2.25 a



CL >= PDTL

FIG 2.25 b



CL >= PDTL

Case I $CL \geq PDTL$ and $Ang = \varnothing$

An instance of the case is shown in fig. 2.25b. The cutter is placed such that point 3 of cutter coincides with point a of the feature . If no tool-part interference occurs at the location then the feature is machinable with the given cutter provided it also satisfies the condition

$$Y_{max} \leq PY[1]$$

If the tool part interference occurs at the location then the same cutter is placed at the lower end of the partial dovetail such that point b of the feature coincides with point 4 of the cutter & checked for tool-part interference. An instance of the case is shown in fig. 2.25c. If no tool-part interference occurs then the cutter is suitable to machine the given feature provided it also satisfies the condition

$$Y_{max} \leq PY[1]$$

Case II $CL < PDTL$ & $Ang = \varnothing$

The cutter is checked for tool-part interference at two locations. At first location, point a of the feature coincides with the point 3 of the cutter and at second location point b of the feature coincides with point 4 of the cutter. If no tool-part interference occurs and the condition

$$Y_{max} \leq PY[1]$$

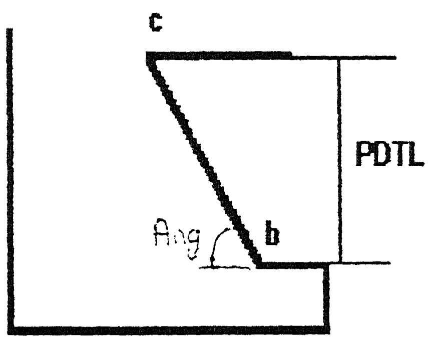
is satisfied then the feature is machinable with the given cutter.

2.4.10 CHECKING THE MACHINABILITY OF A PARTIAL RIGHT DOVETAIL

When an instance of a partial right dovetail is encountered then the list of dovetail cutter is scanned to find a cutter to machine the feature. Each cutter is checked for tool-part interference. If more than one cutter is found to be suitable then the one requiring minimum number of passes is chosen. A partial right dovetail and the terminology used is shown in fig 2.26. Terminology used for dovetail cutter is same as that explained in figure 2.16b.

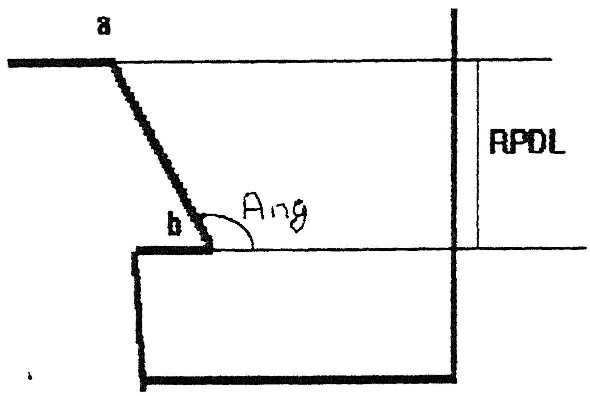
Case I $CL \geq PDTL$ & $Ang = \varnothing$

The cutter is first checked for tool part interference at the



A partial right dovetail

FIG 2.26



A partial left reverse dovetail

FIG 2.27 a

feature. If the tool-part interference is not present then the tool is chosen .

If the tool-part interference exists then the same cutter is checked for tool-part interference at the location where point a of the feature coincides with point 5 on the cutter .

<u>Case II</u> CL < PDTL and Ang = ø

The cutter is checked for tool part interference at two locations . At first location the point b of the feature coincides with point 6 of the cutter . At second location point a of the feature coincides with point 5 of the cutter .

For the above two cases the additional condition to be satisfied is

$$Y_{max} \leq PY[1]$$

<u>2.4.11 CHECKING THE MACHINABILITY OF A PARTIAL LEFT REVERSE DOVETAIL</u>

A partial left reverse dovetail can be machined by three types of cutters .

(1) Reverse dovetail cutter

(2) Single angle cutter

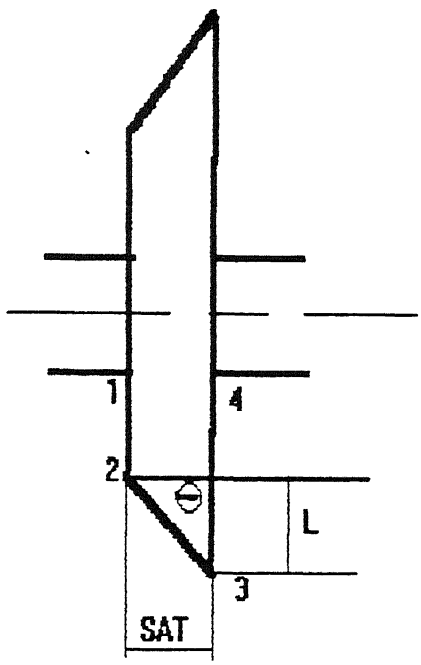
(3) V-slot cutter

Therefore when an instance of a partial left reverse dovetail is encountered then the list of all these three cutters is scanned to find a suitable cutter . If more than one cutter is found suitable then the one requiring minimum number of passes is selected .

A partial left reverse dovetail and a single angle cutter is shown in figure 2.27a and 2.27b respectively. The terminology used is also explained in the figure . Terminology used for reverse dovetail is same as explained in figure 2.18b. Terminology used for V-slot cutter is same as explained in fig. 2.20b.

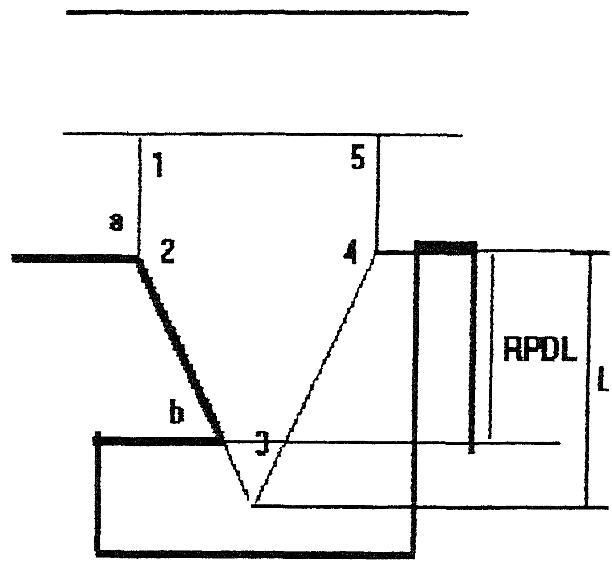
<u>Case I</u> CL ≥ RPDL and Ang = ø

The cutter is first checked for tool part interference at the top of the feature i.e point 3 on the reverse dovetail cutter (point 2 for V-slot or single angle cutter) coincides with point a on the feature .



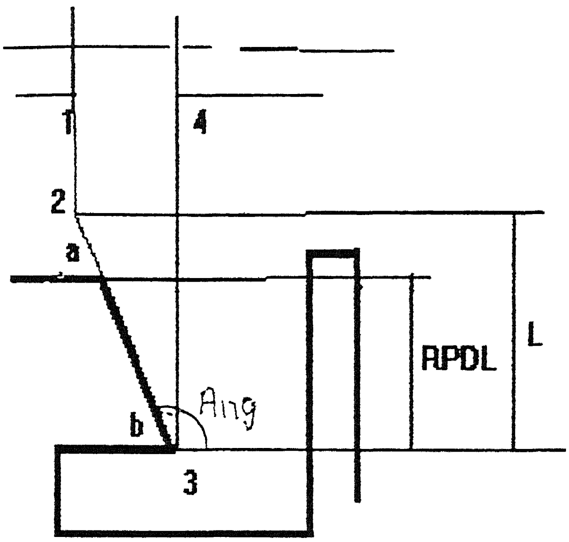
A single angle cutter

FIG 2.27 b



CL >= L

FIG 2.27 c



CL >= RPDL

FIG 2.27d

An instanced of the above example is shown in fig. 2.27c (the cutter shown is a V-slot cutter). The cutter is chosen if no tool part interference exit at the location.

If tool part interference exists at the above discussed location then the same cutter is checked for machinability at a location were point b on the feature coincides with point 4 of the reverse dovetail cutter (point 3 for V-slot or single angle cutter). If no tool part interference exists then the cutter is chosen and the code of the cutter is noted. An instance of this case is shown in fig. 2.27d (cutter shown is a single cutter).

<u>Case</u> <u>II</u> CL < RPDL and Ang = ø

The cutter is checked for tool part interference at two locations . At first location the point a of the feature coincides with point 3 of the reverse dovetail cutter (point 2 for V-slot cutter or single angle cutter) and at the second location the point b on the feature coincides with point 4 of the reverse dovetail cutter (point 3 for V-slot cutter or single angle cutter).

For the above two cases the additional condition to be satisfied is

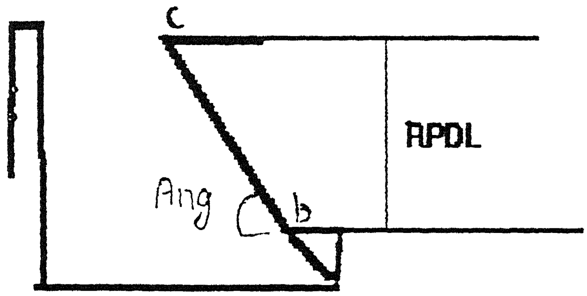
$$Y_{max} \leq PY[1].$$

Where PY[1] is the value of Y coordinate of point 1 of the cutter used.

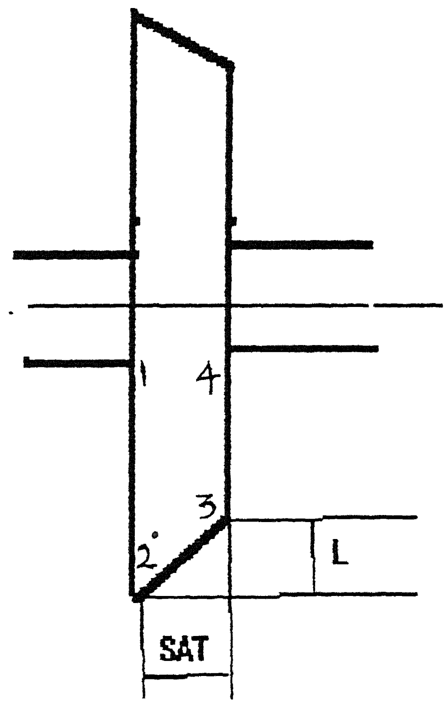
2.4.12 CHECKING THE MACHINABILITY OF A PARTIAL RIGHT REVERSE DOVETAIL

A partial right reverse dovetail is also machinable by three cutters as in the case of partial left reverse dovetail.

Therefore when an instance of a partial right reverse dovetail is encountered then the list of all the three cutters is scanned to find a suitable tool. Fig. 2.28 shows a partial right



A partial right reverse dovetal



A single angle cutter

FIG 2.28

Case I $\quad CL \geq RPDL$ and $Ang = \theta$

The Tool cutter is checked for machinability first at the top portion of the feature, i.e., point 6 of the reverse dovetail cutter (point 4 for a V-slot cutter and point 3 for a single angle cutter) is coincided with point c of the feature. If no tool part interference takes place then it is chosen otherwise it is checked at the bottom of the feature, i.e., point 5 of the reverse dovetail cutter (point 3 for the V-slot cutter and point 2 for a single angle cutter) is coincided with point b of the feature.

Case II $\quad CL < RPDL$ and $Ang = \theta$

The cutter is checked for machinability at the top portion and then at the bottom portion.

for the above two cases the additional condition to be satisfied is

$$Y\ max \leq PY[1]$$

CALCULATION OF NUMBER OF PASSES AND CUTTER POSITION AT EACH PASS

In the previous section, machinability of each feature was checked and if found machinable then the cutter code was noted along with the feature . In this section the methodology used for calculating the number of passes and determining the position of cutter at each pass is discussed . Information about the cutter position is maintained in the form of X and Y coordinates of any point on the cutter . For example, in the case of a T -slot cutter the X and Y coordinates of point 3 on the cutter is stored for each pass, along with the pass number to give the information about the cutter location for that pass . This cutter location is used afterwards for generating n-c part program for machining the part .

3.1 T - SLOT

The calculation of number of passes required for machining a T - slot is as follows .

The length TSW of the feature is divided by the cutter diameter CD (refer to figure 3.1a). If the result is not an integer then it is rounded off to the next greater integer . This gives the number of passes required to machine one layer of the T-slot . To find the number of layers to be removed, the feature length TSL is divided by the cutter length CL . Again if the result is not an integer then it is rounded off to the next greater integer .

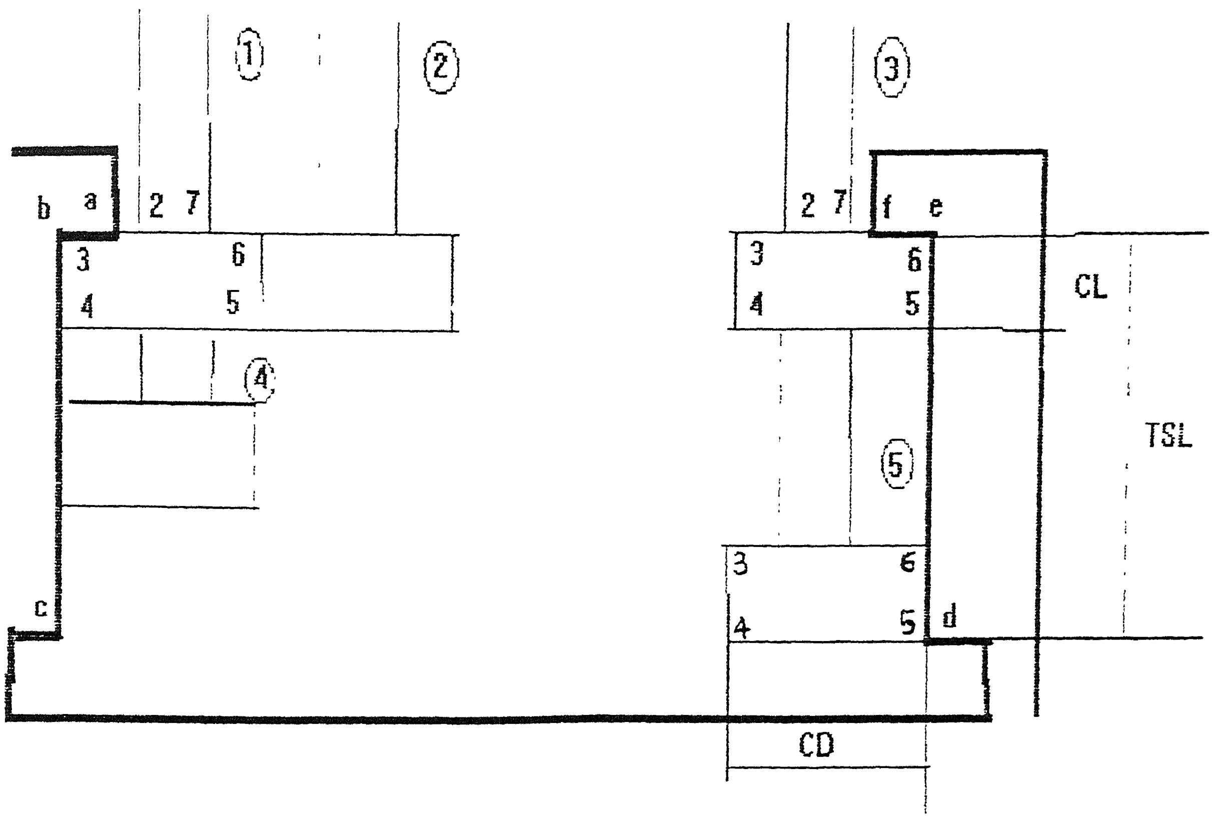
If the number of passes required per layer = N

and the number of layers to be removed = M

Then total number of passes required to machine the T - slot =

$$N \times M$$

For the first pass the T - slot cutter is positioned at the left extreme such that point 3 of cutter coincides with point b of the feature . The value of X and Y coordinates of point 3 of cutter is noted along with the pass number which is 1 presently



Calculation of number of passes for a T-slot

FIG 3.1 a

These values of X and Y coordinate give the information regarding the position of the cutter and are used afterwards to write nc part program for the part . The cutter location for pass number 1 corresponds to position 1 in the figure 3.1a. For subsequent passes the cutter is shifted each time by a distance CD towards the right . Hence new X coordinate value of point 3 for the new pass would become

X coordinate value for the previous pass + CD.

Y co-ordinate does not change for a layer . In the figure the cutter location for pass number 2 is marked as 2 . For every pass the X and Y coordinate values are stored along with the pass number. For the N^{th} pass i.e the last pass in layer 1, the cutter will touch the right extreme of the T - slot . Hence X-coordinate of point 3 on the cutter would become X[e] - CD. This corresponds to position 3 in the figure 3.1a (X[e] is the value of X co-ordinate of point e of the feature).

The above step removes the first layer of the T - slot .

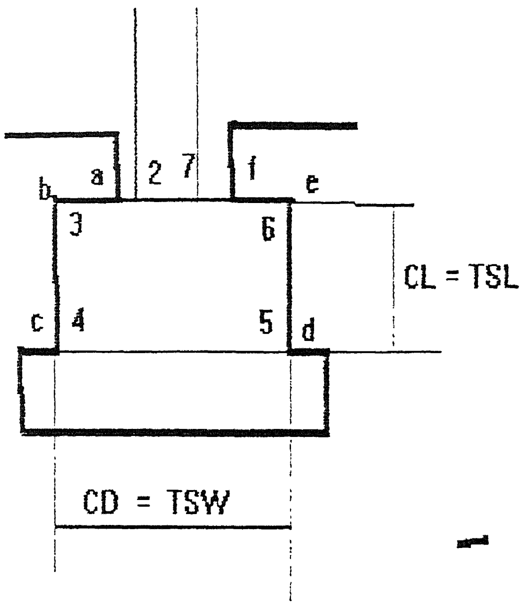
For the next layer (assuming that it is not the last layer) the cutter is moved by a distance CL towards the bottom of the slot . For the first pass of this layer the cutter is located at the left extreme of the T - slot . Therefore the X coordinate of point 3 on the tool for this pass would be X[b] and the value of Y coordinate for the layer would be

value of Y coordinate for previous layer - CL .

For subsequent passes in the layer the cutter is moved towards the right in the same way as in layer 1 and the X and Y coordinates are noted for all the passes . cutter location for one of the intermediate pass is shown at position 4 in the figure .

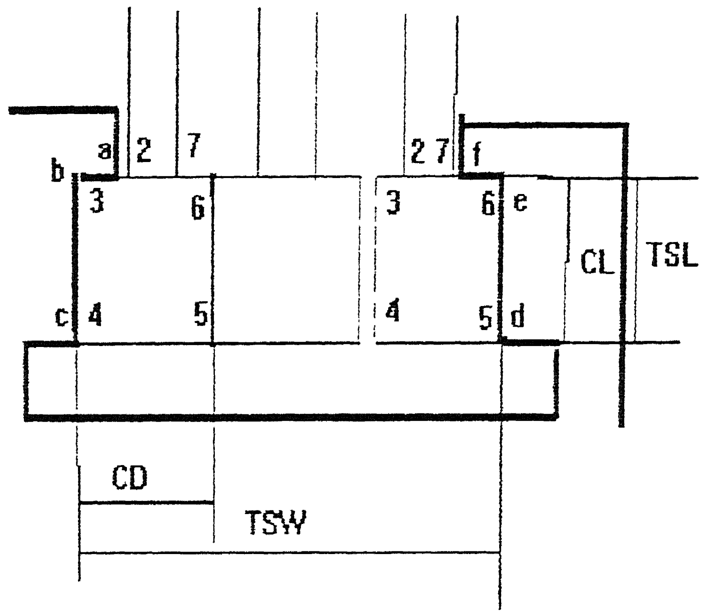
Except the last layer, all the layers are removed in the same way.

For the last layer the cutter would touch the bottom portion of the slot . Hence the Y coordinate of the point 3 on the cutter for this layer would be Y[c] + CL . For the first pass in this layer, the cutter would be placed at the left extreme therefore the X coordinate for point 3 would be X[b] . Subsequent steps are same as that for previous layers . The cutter position during the last pass is shown at the location 5 in the figure .



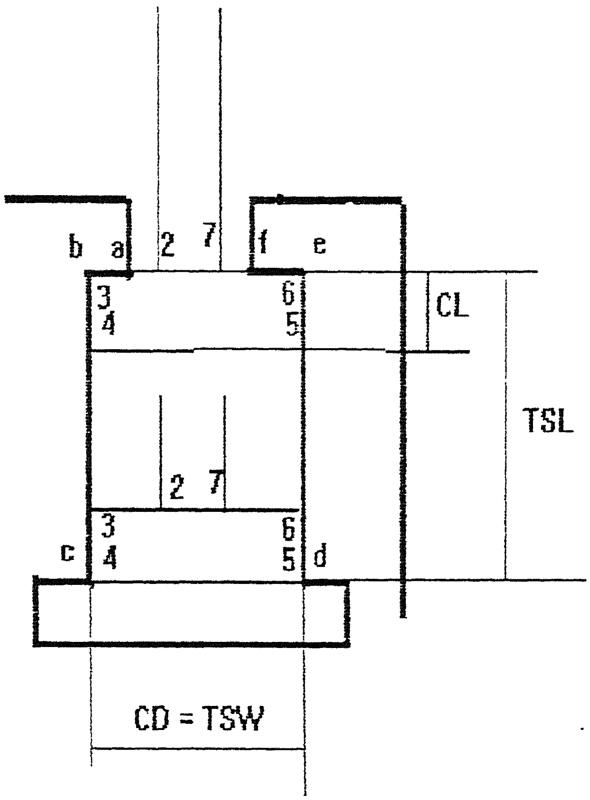
CD = TSW , CL = TSL

FIG 3.1 b



CD < TSW , CL >= TSL

FIG 3.1 c



CD = TSW , CL < TSL

FIG 3.1 d

SPECIAL CASES

CASE 1

number of layers = 1

number of passes per layer = 1

This case arises when CL ≥ TSL and CD = TSW . Only one pass is required to machine the feature . An example is shown in figure 3.1b.

CASE 2

number of layers = 1

number of passes per layer > 1

This case arises when CL ≥ TSL and CD < TSW . Movement of the cutter while machining the layer is same as discussed in the general case . An example is shown in figure 3.1c.

CASE 3

number of layers > 1

number of passes per layer = 1

This case arises when CL < TSL and CD = TSW . An example is shown in figure 3.1d.

3.2 VERTICAL SLOT

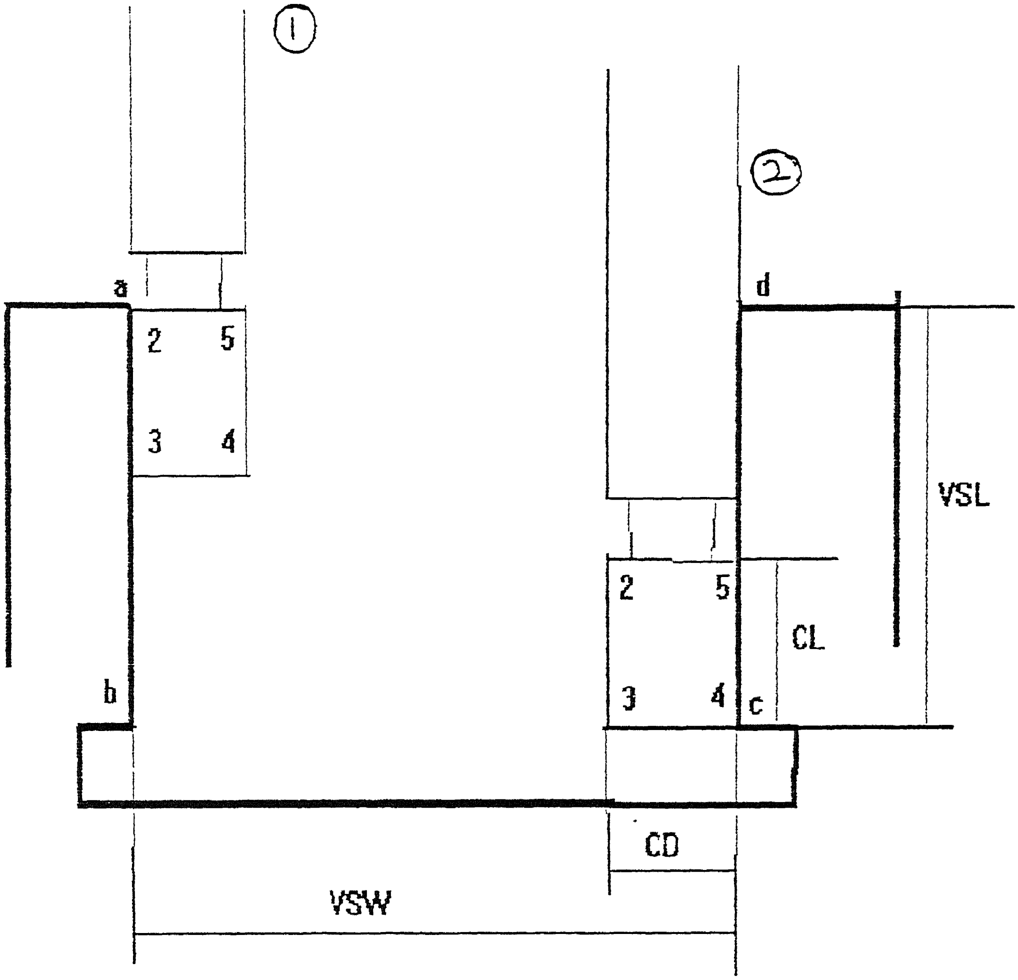
The calculation of number of passes in this case is similar to that of T - slot . Only difference is that the cutter chosen for machining the vertical slot can be a T -slot cutter or an end mill cutter . The number of layers to be machined is calculated by dividing VSL by cutter length CL (refer to figure 3.2a). If the result is not an integer then it is rounded to the next bigger integer . The number of passes per layer is calculated by dividing VSW by cutter diameter CD. If the result is not an integer then it is rounded of to the next bigger integer .

If number of layers to be machined = M

If number of passes per layer = N

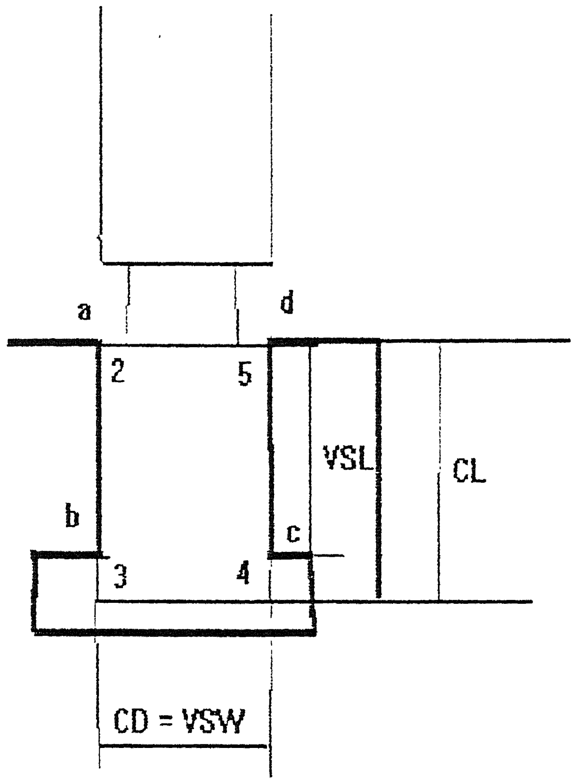
then the total no of passes = $M \times N$

For the first pass the cutter is placed at the top of the



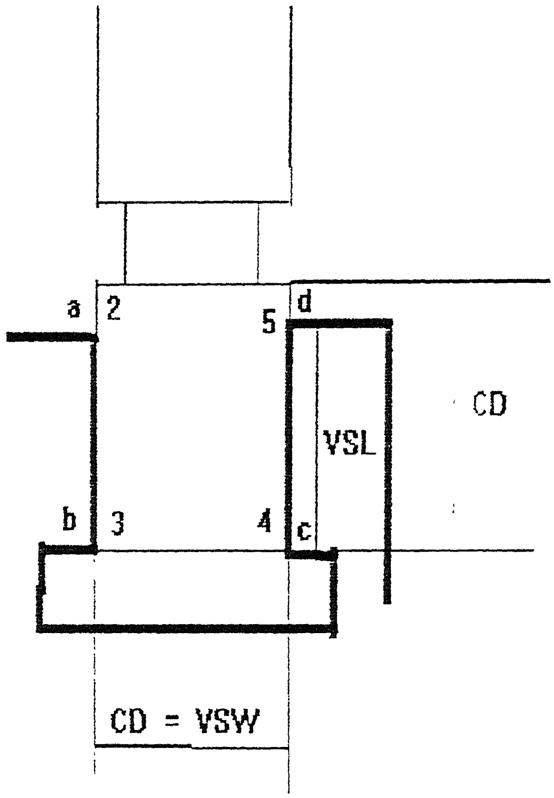
Calculation of number of passes for a vertical slot

FIG 3.2 a



CD = VSW , CL > VSL

FIG 3.2 b



CD = VSW ,CL > VSL

FIG 3.2 c

vertical slot so that point a on the slot coincides with point 2 on the cutter as shown in position 1 of the figure 3.2a. The subsequent motion of of the cutter is same as discussed in the case of T-slot . For every pass, the pass number and corresponding X and Y coordinate of the point 2 on the cutter is noted . The position of the cutter for the last pass is shown at location 2 in the figure 3.2a. The figure shows an end mill cutter machining the vertical slot . As stated earlier it could be a T-slot milling cutter also .

SPECIAL CASES

CASE 1

number of layers = 1

number of passes per layer = 1

This occurs when CL ≥ VSL and CD = VSW . The feature is machinable in one pass

Two situation arise for the given condition

(1) If the feature is machinable with cutter at the top of the vertical slot (refer to section 2.4.6 case 1) then the point 2 on cutter coincides with point a of the vertical slot .Hence the X and Y coordinate of point 2 would be same as that of point a on the feature. An example is shown in figure 3.2b.

(2) If the feature is machinable with cutter at bottom then the point 4 on cutter coincides with point b on the cutter . The Y coordinate of point 3 would be Y[b] + CL . X coordinate would be same as X[a] .An example is shown in figure 3.2c.

CASE 2

number of layers = 1

number of passes per layer > 1

this case occurs when CL ≥ VSL and CD < VSW . As in case 1 here also two situation arise :

(1) If the feature is machinable with cutter at the top of the vertical slot then point 2 on the cutter would coincide with point a on the feature for the first pass . The value of Y co-ordinate for all the passes of the layer would be Y[a] .

(2) If the feature is machinable with cutter at the bottom of

the vertical slot then the point 3 on cutter would coincide with point b on the feature . The value of Y coordinate for all the passes in the layer would be Y[b] + CL .

The calculation of value of X coordinates for the various passes of the layer is same as discussed in general case .

CASE 3

number of layers > 1

number of passes per layer = 1

This occurs when CL < VSL and CD = VSW .

3.3 DOVETAIL

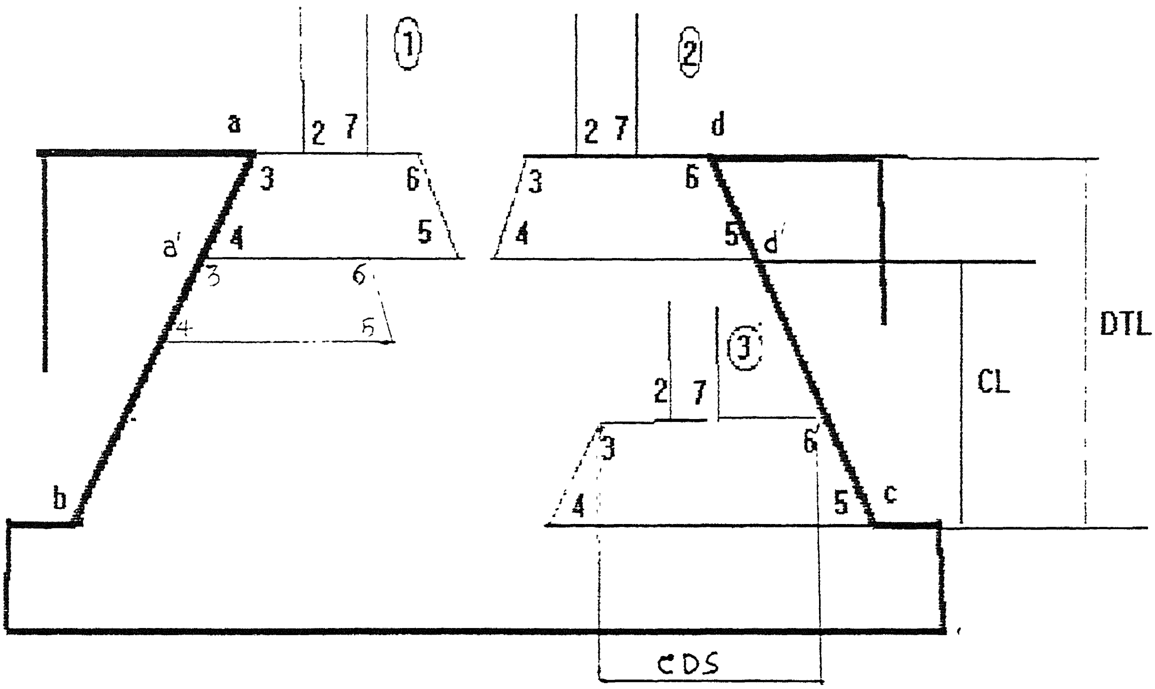
The number of layers to be machined is calculated by dividing DTL by cutter length CL (refer to figure 3.3) . In the case of a dovetail, each layer will have different number of passes .

For calculating the number of passes for the first layer, the distance (X[d] - X[a]) is calculated and divided by cutter diameter at the smaller end i.e CDS . If the result is not an integer then it is rounded off to the next greater integer . The cutter for pass number 1 is located at the extreme left of the top portion of the dovetail feature as shown in position 1 of the figure 3.3.The point 3 on the cutter coincides with point a on the feature . The pass number and the X and Y coordinates of the point 3 are noted .for subsequent passes in the same layer the cutter is moved by distance CDS towards right after each pass . Therefore the value of X coordinate of point 3 for a new pass would be

value of X coordinate for previous pass + CDS .

Y coordinate for all the passes of the layer remain same. For the last pass in the layer the cutter should touch the right side of the feature . Therefore the value of X coordinate of point 3 for this pass would be X[d] - CDS . This location of the cutter corresponds to position 2 in the figure 3.3.

For calculating the number of passes in the next layer (assuming that it is not the last layer), the cutter is moved by a distance CL downwards . Hence the value of Y coordinate of point 3 on the cutter for all the passes in the layer would be



Calculation of number of passes for a dovetail

FIG 3.3 a

value of Y coordinate of point 3 for previous layer - CL . Now a horizontal line is drawn through point 3 of the cutter and the value of X coordinates of its points of intersection with side ab and cd of the feature is calculated . The difference between the X coordinates of these two points is calculated . This difference when divided by CDS gives information about the number of passes for this layer . The movement of cutter towards the right is same as that discussed for layer 1 .

Figure shows the calculation of number of passes for second layer . The line through point 3 intersects the line ab at a′ and line cd at d′ . Value of (X[d′] - X[a′]) divided by CDS gives the value of the number of passes . If the value is not an integer then it is rounded off to the next bigger integer .

For the last layer the cutter should touch the bottom portion of the feature . Therefore the value of Y coordinate for all the passes in this layer would be Y[b] + CL . Calculation of number of passes and the movement of cutter would be same as for other layers . Position 3 in the figure 3.3 gives the location of cutter for the last pass .

SPECIAL CASES

CASE 1

number of layers = 1

number of passes per layer = 1

This case arises when CL ≥ DTL .

Two situations arise here

(1) If the cutter chosen has been checked for machinability at the top of the feature (refer to section 2.4.3) then the point 3 on the cutter coincides with point a on the dovetail . Hence coordinates of point 3 would be same as that of point a .

(2) If the cutter chosen has been checked for machinability at the bottom of the feature then

value of Y coordinate of point 3 on cutter = Y[b] + CL

value of X coordinate of point 3 on cutter =

X[b] + (CD - CDS) / 2

CASE 2

number of layers = 1

number of passes per layer > 1

This occurs when CL ≥ DTL .

Similar to case 1, two situations arise here also

(1) If the cutter chosen has been checked for machinability at the top of the feature then for all the passes the value of Y coordinate of point 3 on cutter would be Y[a] . Calculation of X coordinates is same as discussed for general case .

(2) If the cutter has been checked for machinability at the bottom of the feature then

value of Y coordinate of point 3 for all the passes = Y[b] + Cl

value of X coordinate of point 3 for first pass =

X[b] + (CD - CDS) / 2

Calculation of X coordinates of point 3 for subsequent passes is same as discussed in general case .

3.4 REVERSE DOVETAIL

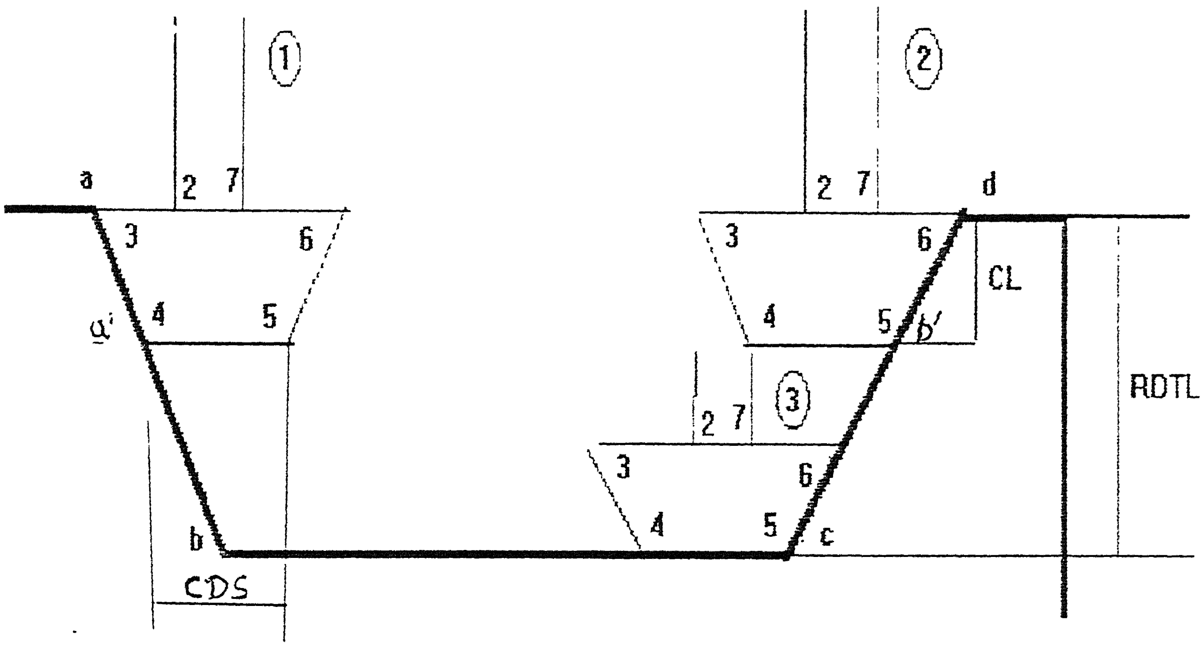
The steps for calculating the number of passes and corresponding location of the cutter is similar to that in dovetail . The number of layers is calculated by dividing RDTL by the cutter length CL (refer to figure 3.4).

For the first layer the point 3 on the cutter is coincided with point 1 on the feature . For the calculation of number of passes for the layer, a horizontal line is drawn through point 4 of the cutter . The X coordinates of the points of intersection (a′ and b′ in the fig. 3.4) of the horizontal line and the line ab and cd is calculated . The difference between the values of the two X coordinates divided by the cutter diameter at the smaller side i.e CDS gives the number of passes for the layer . The movement of cutter towards right end after each pass is same as discussed in the case of dovetail .

For subsequent layers the cutter is shifted towards the bottom by a distance CL after each layer. Calculation of number of passes and values of X and Y coordinates for various passes are same as that for first layer .

The figure 3.4 shows the position of cutter at different locations.

Location 1 corresponds to pass number 1



Calculation of number of passes for a reverse dovetail

FIG 3.4

Location 2 corresponds to last pass in layer 1

Location 3 corresponds to last pass

SPECIAL CASES

CASE 1

number of layers = 1

number of passes per layer = 1

This occurs when CL ≥ RDTL . Two situations arise in this case also:

(1) If the cutter chosen has been checked for machinability at the top of the feature (refer to section 2.4.4) then the value of X and Y coordinates for point 3 would be same as that of point a on the feature .

(2) If the cutter chosen has been checked for machinability at the bottom of the feature then

value of Y coordinate for point 3 on the cutter = Y[b] + CL

value of X coordinate for point 3 on the cutter = X[b] - (CD - CDS) / 2

CASE 2

number of layers = 1

number of passes per layer > 1

This case arises when CL ≥ RDTL . Two situations arise here

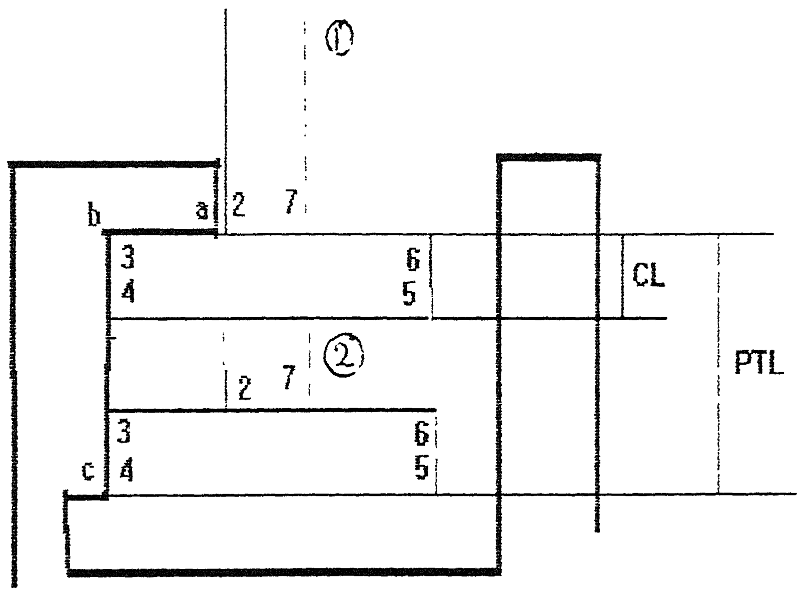
(1) If the machinability has been checked at the top portion then value of Y coordinates of point 3 for all the passes = Y[a] value of X coordinates are calculated as discussed above for the general case.

(2) If the machinability has been checked at the bottom of the feature then

value of Y coordinate of point 3 on the cutter for all the passes = Y[b] + CL

value of X coordinate of point 3 on the cutter for first pass = X[b] - (CD - CDS) / 2

values of X coordinates of point 3 for subsequent passes is same as discussed for the general case .



Calculation of number of passes for a partial left T-slot

FIG 3.5

3.5 V - SLOT

V-slot is machined in just 1 pass by a V-slot cutter . For a V-slot cutter the coordinates of point 2 are noted to maintain the information about the position of the tool (refer to figure 2.20b).

The value of X coordinate for the point 2 on the cutter =

$$X[b] - VST / 2$$

The value of Y coordinate for the point 2 on the cutter =

$$Y[b] + VST / (2 \times \tan(Ang))$$

3.6 PARTIAL LEFT T - SLOT

The number of passes for partial left T-slot is calculated by dividing PTL (refer to figure 3.5) by cutter length CL. If the result is not an integer then it is rounded to the next higher integer .

For The first pass (shown at location 1 in the figure 3.5) the cutter is located at the top of the feature i.e point 3 on cutter coincides with point b on the feature. Values of X andand Y coordinates of point 3 are noted . For subsequent passes the value of X coordinate of point 3 does not change . Value of Y coordinate of point 3 on the cutter for each new pass would be

value of Y coordinate of point 3 for previous pass - CL.

For the last pass (shown at location 2 in the figure) value of Y coordinate would be Y[c] + CL .

SPECIAL CASE

number of pass = 1

This occurs when CL ≥ PTL

X and Y coordinate of point 3 is same as that of point b on feature .

3.7 PARTIAL RIGHT T - SLOT

number of calculation of passes is same as that in the case of partial left T - slot . The value of X coordinate of point 3 on the cutter for all the passes is X[c] - cutter diameter CD.

The value of Y coordinate for the first pass is Y[c] . For each subsequent pass the Value of Y coordinate will go on decreasing as in the case of partial left T - slot . The value of Y coordinate of point 3 for the last pass would be Y[b] + CL .

SPECIAL CASE

number of pass = 1

This occurs when CL ≥ PTL. The value of X and Y coordinate is same as that for first pass of the general case discussed above.

3.8 PARTIAL LEFT DOVETAIL

The number of passes is calculated by dividing PDTL (refer to figure 2.25a) by cutter length CL . If the value is not an integer then it is rounded off to the next greater integer. For the first pass the point 3 on the cutter is coincided with point a on the feature. For subsequent passes the cutter is moved downwardsby a distance of CL each time . Hence for each new pass the value of Y coordinate for point 3 would be

Value of Y coordinate for the previous pass - CL .

Value of X coordinate for each new pass would be

Value of X coordinate of point 3 for previous pass - (CD - CDS) / 2

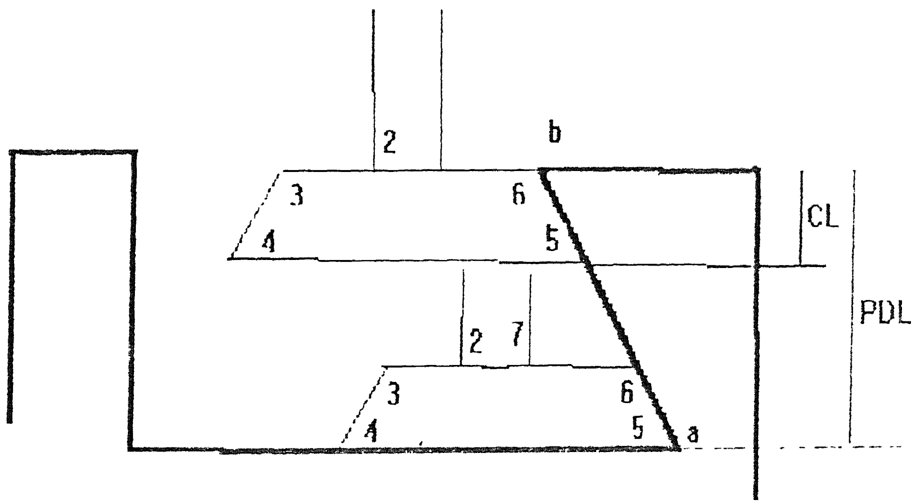
For the last pass the point 4 on the cutter is coincided with point b on the feature and the coordinates of point 3 are calculated .

SPECIAL CASE

number of pass = 1

This occurs when CL ≥ PDTL .

Calculation of X and Y coordinates of point 3 is exactly same as that discussed for dovetail special case 1 .



Calculation of number of passes for a partial right dovetail

FIG 3.6

3.9 PARTIAL RIGHT DOVETAIL

The calculation of number of passes is same as that for partial left dovetail . For the first pass the point 6 on the cutter is coincided with point b on the feature(refer to figure 3.6 location 1). Value of X coordinate for the pass then would be X[b] - CDS . value of Y coordinate would be Y[b].For subsequent passes the value of X coordinate of point 3 on the cutter would be

value of X coordinate for previous pass + (CD - CDS) / 2

value of Y coordinate would be

value of Y coordinate for previous pass - CL .

For the last pass the point 5 on the cutter is coincided with point a on the feature and the values of the coordinates are calculated (refer to figure 3.6 location 2) .

SPECIAL CASE

no of pass = 1

this occurs when CL ≥ PDTL .

If the machinability was checked at the top of the feature (refer to section 2.4.10) then the cutter point 6 is coincided with point b for the pass .

If the machinability was checked at the bottom then point 5 on the cutter is coincided with point a on the feature .

3.10 PARTIAL LEFT REVERSE DOVETAIL

Number of passes is calculated by dividing RPDL (refer to figure 2.27a) by CL (L for V-slot and single angle cutter).For the first pass point 3 of cutter is coincided with point a on the feature . For subsequent passes the cutter is moved by a distance CL each time . Value of X coordinate for each new pass would be

value of X coordinate for the previous pass + (CD - CDS) / 2

For the last pass the point 4 on the cutter is coincided with point c on the feature and coordinate values are calculated .

If the cutter considered for machining the feature is a V-slot cutter or equal angle cutter then for the first pass point 2 on the cutter is coincided with point a on the feature . For subsequent passes the cutter is moved by distance L downwords

(refer to figure 2.20b).

value of X coordinates of point 2 on the cutter for each new pass (for V-slot cutter) = value of X coordinate for the previous pass + VST / 2 (refer to figure 2.20b for terminology).

value of X coordinate of point 2 on the cutter for each new pass (for equal angle cutter) would be

value of X coordinate for the previous pass + SAT (refer to fig. 2.27b for terminology).

For the last pass the point 2 on the feature is coincided with point c on the cutter.

SPECIAL CASE

number of passes = 1

this arises when CL (or L for V-slot cutter and equal angle cutter) ≥ RPDL .

If the machinability has been checked on the top side of the feature (refer to section 2.4.11) then point 3 on the reverse dovetail cutter (point 2 for V-slot cutter and equal angle cutter) are coincided with point a for the pass .

If the machinability has been checked on the bottom side then the point 4 on the reverse dovetail cutter(point 3 for V-slot cutter and equal angle cutter) are coincided with point c on the feature .

3.11 PARTIAL RIGHT REVERSE DOVETAIL

Number of passes is calculated in the same way as in the case of partial left reverse dovetail.

For the first pass the point 6 on the reverse dovetail cutter (point 4 for V-slot cutter and point 3 for single angle cutter) is coincided with point c on the feature (refer to figure 2.28).
For subsequent passes the cutter is moved by a distance CL (L for V-slot and single angle cutters) downwards until it reaches the bottom of the feature.

For the last pass the point 5 on the reverse dovetail cutter (point 3 for V-slot and point 2 for single angle cutter) is coincided with point b on the feature.

SPECIAL CASE

Number of passes = 1

This case arises when CL ≥ RPDL

(L for V-slot and single angle cutter)

If the cutter has been checked for machinability at the top of the feature then the point 6 on the reverse dovetail cutter (point 4 for V-slot cutter and point 3 for single angle cutter) is coincided with point cof the feature for the first pass.

If the cutter has been checked for machinability at the bottom then point 5 of the reverse dovetail (point 3 for V-slot cutter and point 2 for single angle cutter) is coincided with

3.12 MERGING PARTIAL FEATURES

Some of the partial features recognised by the system could be merged into complete features. This would help in minimizing the number of tool changes and number of passes as now the merged feature can be machined with a single cutter in one setting.

The various conditions to be satisfied for merging partial features are discussed below.

3.12.1 MERGING PARTIAL T - SLOT

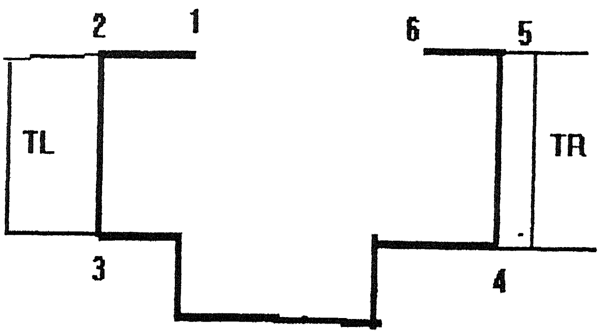
The methodology discussed here for merging partial T- slots is for the top side. For other side the points have to be separated suitably about the point (0, 0) If a partial left T-slot and a partial right T- slot has been recognized and they satisfy the following conditions (Ref. to fig.3.7).

$$y[2] = y[5] \text{ and } TL = TR$$

and the feature 1, 2, 3, 4, 5 and 6 is machinable, then they form a complete T- slot.

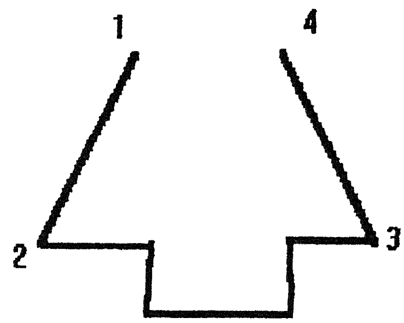
3.12.2 MERGING PARTIAL DOVETAIL

The methodology discussed here, for merging partial dovetail



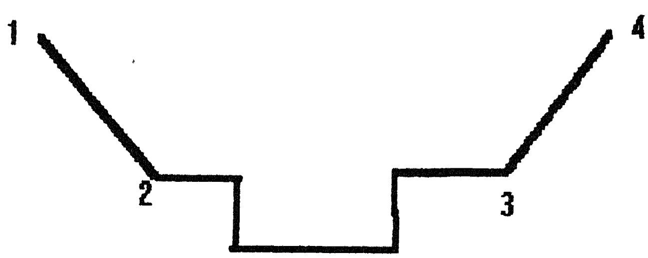
Merging partial T-slots

FIG 3.7



Merging partial dovetails

FIG 3.8



Merging partial reverse dovetails

FIG 3.9

is for the top side. For other sides the points have to be rotated suitably about point (0, 0).

If a partial left dovetail and a partial right dovetail has been recognized and they satisfy the following conditions (fig 3.8

$$Y[2] = Y[3],\ Y[1] = Y[4] \quad \text{and} \quad Ang1 = Ang2$$

and the feature 1, 2, 3 and 4 is machinable then they form a complete dovetail.

3.12.3 MERGING PARTIAL REVERSE DOVETAIL

The methodology discussed here, for merging partial reverse dovetail, is for the top side.

If a partial right left dovetail and a partial right dovetail has been recognized and they satisfy the following conditions (Ref. to fig.3.8).

$$Y[2] = Y[3],\ Y[1] = Y[4] \quad \text{and} \quad Ang1 = Ang2$$

and feature 1, 2, 3 and 4 is machinable, then they form a reverse dovetail.

3.13 SEQUENCING AND GENERATION OF NC - PART PROGRAM

The sequence of the machining operations is done by comparing the Y coordinates of the various features on a side. The feature whose any point has maximum value of Y coordinate among all the features i.e the topmost feature is selected for machining first.The rest of the features follow in the decreasing order of the maximum value of Y coordinate .

While calculating the number of passes required to machine a recognized feature we also noted the pass number, corresponding X and Y co- ordinates of a particular point on the cutter and the cutter code.

The user is asked to feed in the spindle speed and the feed rate for each tool used for machining. These information are used to generate nc- part program for machining the part.

CHAPTER IV

CONCLUSIONS AND SUGGESTIONS FOR FUTURE WORK:

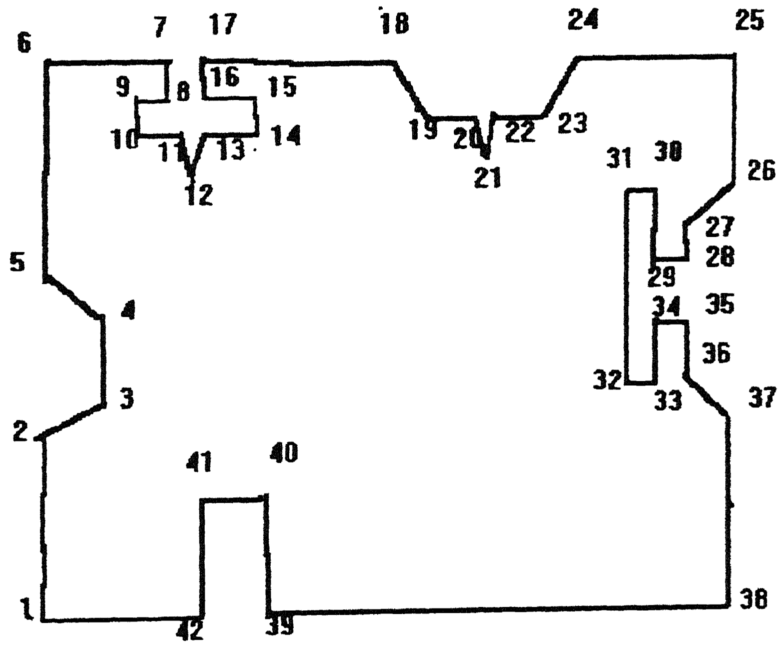
In the present work, feature recognition algorithms have been developed and implemented for 2.5-D prismatic parts. The algorithms have been developed using the boundary representation of the geometry of 2.5-d prismatic parts. The system gives a feasible machining sequence for the parts specifies the tools required and generates n c part program. It gives the dimensions of the stock to be used for getting the part. The developed algorithms have been implemented in pascal language in Unix environment.

The present implementation has some limitations. Presently the system. is not able to recognize circular feature or holes in the part. Future work can be directed towards achieving the same. The sequence of machining generated by the program may not be the optimal one. Improvements are possible to include algorithms which could decrease the number of passes required for machining and the number of tool changes.

The system takes the input in the form of coordinates therefore the part drawings has to carry the information about the values of cordinates of each point on the base plane.

For simplicity The system makes the assumption that the diameter of the T-slot,dovetail and reverse dovetail cutters at the neck portion is equal to shank diameter.

In the discussed system sometimes only the half portion of the tool is required to machine some features (specially during the last pass of a layer or during all the passes of the last layer). This could develop heavy stresses in the cutters. The system could be designed such that the cutter positions for various passes are calculated in a way that minimizes the stress in the cutters.



An example of a part to be machined

FIG 4

```
Script started on Fri Aug 13 09:56:35 1993
[rkv] a.out

begin
if you want to give input through file then press 1 else press 0
1

if the input is through file no 1 then press 1
if the input is through file no 2 then press 2
if the input is through file no 3 then press 3
if the input is through file no 4 then press 4
if the input is through file no 5 then press 5
5

the contents of the file are
x[  1] :    0.000   y[  1] :    0.000
x[  2] :    0.000   y[  2] :   20.000
x[  3] :    5.000   y[  3] :   25.000
x[  4] :    5.000   y[  4] :   45.000
x[  5] :    0.000   y[  5] :   50.000
x[  6] :    0.000   y[  6] :  100.000
x[  7] :   20.000   y[  7] :  100.000
x[  8] :   20.000   y[  8] :   95.000
x[  9] :   14.000   y[  9] :   95.000
x[ 10] :   14.000   y[ 10] :   90.000
x[ 11] :   24.000   y[ 11] :   90.000
x[ 12] :   25.000   y[ 12] :   85.000
x[ 13] :   26.000   y[ 13] :   90.000
x[ 14] :   36.000   y[ 14] :   90.000
x[ 15] :   36.000   y[ 15] :   95.000
x[ 16] :   30.000   y[ 16] :   95.000
x[ 17] :   30.000   y[ 17] :  100.000
x[ 18] :   45.000   y[ 18] :  100.000
x[ 19] :   50.000   y[ 19] :   95.000
x[ 20] :   60.000   y[ 20] :   95.000
x[ 21] :   61.000   y[ 21] :   90.000
x[ 22] :   62.000   y[ 22] :   95.000
x[ 23] :   72.000   y[ 23] :   95.000
x[ 24] :   77.000   y[ 24] :  100.000
x[ 25] :  100.000   y[ 25] :  100.000
x[ 26] :  100.000   y[ 26] :   85.000
x[ 27] :   95.000   y[ 27] :   80.000
x[ 28] :   95.000   y[ 28] :   75.000
x[ 29] :   90.000   y[ 29] :   75.000
x[ 30] :   90.000   y[ 30] :   69.000
x[ 31] :   88.000   y[ 31] :   69.000
x[ 32] :   88.000   y[ 32] :   49.000
x[ 33] :   90.000   y[ 33] :   49.000
x[ 34] :   90.000   y[ 34] :   55.000
x[ 35] :   95.000   y[ 35] :   55.000
x[ 36] :   95.000   y[ 36] :   45.000
x[ 37] :  100.000   y[ 37] :   40.000
x[ 38] :  100.000   y[ 38] :    0.000
x[ 39] :   50.000   y[ 39] :    0.000
x[ 40] :   50.000   y[ 40] :   10.000
x[ 41] :   40.000   y[ 41] :   10.000
x[ 42] :   40.000   y[ 42] :    0.000

if you want to change whole file write 1
if you want to change a particular value write 2
if you want to view the coordinates in the file write 3
```

```
x[  1] :   0.000    y[  1] :   0.000
x[  2] :   0.000    y[  2] :  20.000
x[  3] :   5.000    y[  3] :  25.000
x[  4] :   5.000    y[  4] :  45.000
x[  5] :   0.000    y[  5] :  50.000
x[  6] :   0.000    y[  6] : 100.000
x[  7] :  20.000    y[  7] : 100.000
x[  8] :  20.000    y[  8] :  95.000
x[  9] :  14.000    y[  9] :  95.000
x[ 10] :  14.000    y[ 10] :  90.000
x[ 11] :  24.000    y[ 11] :  90.000
x[ 12] :  25.000    y[ 12] :  85.000
x[ 13] :  26.000    y[ 13] :  90.000
x[ 14] :  36.000    y[ 14] :  90.000
x[ 15] :  36.000    y[ 15] :  95.000
x[ 16] :  30.000    y[ 16] :  95.000
x[ 17] :  30.000    y[ 17] : 100.000
x[ 18] :  45.000    y[ 18] : 100.000
x[ 19] :  50.000    y[ 19] :  95.000
x[ 20] :  60.000    y[ 20] :  95.000
x[ 21] :  61.000    y[ 21] :  90.000
x[ 22] :  62.000    y[ 22] :  95.000
x[ 23] :  72.000    y[ 23] :  95.000
x[ 24] :  77.000    y[ 24] : 100.000
x[ 25] : 100.000    y[ 25] : 100.000
x[ 26] : 100.000    y[ 26] :  85.000
x[ 27] :  95.000    y[ 27] :  80.000
x[ 28] :  95.000    y[ 28] :  75.000
x[ 29] :  90.000    y[ 29] :  75.000
x[ 30] :  90.000    y[ 30] :  69.000
x[ 31] :  88.000    y[ 31] :  69.000
x[ 32] :  88.000    y[ 32] :  49.000
x[ 33] :  90.000    y[ 33] :  49.000
x[ 34] :  90.000    y[ 34] :  55.000
x[ 35] :  95.000    y[ 35] :  55.000
x[ 36] :  95.000    y[ 36] :  45.000
x[ 37] : 100.000    y[ 37] :  40.000
x[ 38] : 100.000    y[ 38] :   0.000
x[ 39] :  50.000    y[ 39] :   0.000
x[ 40] :  50.000    y[ 40] :  10.000
x[ 41] :  40.000    y[ 41] :  10.000
x[ 42] :  40.000    y[ 42] :   0.000
press any no. to proceed
3

  0.000  0.000
  0.000 20.000
  5.000 25.000
  5.000 45.000
  0.000 50.000
  0.000100.000
 20.000100.000
 20.000 95.000
 14.000 95.000
 14.000 90.000
 24.000 90.000
 25.000 85.000
 26.000 90.000
 36.000 90.000
 36.000 95.000
 30.000 95.000
```

```
 45.000100.000
 50.000 95.000
 60.000 95.000
 61.000 90.000
 62.000 95.000
 72.000 95.000
 77.000100.000
100.000100.000
100.000 85.000
 95.000 80.000
 95.000 75.000
 90.000 75.000
 90.000 69.000
 88.000 69.000
 88.000 49.000
 90.000 49.000
 90.000 55.000
 95.000 55.000
 95.000 45.000
100.000 40.000
100.000  0.000
 50.000  0.000
 50.000 10.000
 40.000 10.000
 40.000  0.000
  0.000  0.000
```

THE FOLLOWING FEATURES ARE NONMACHINABLE

```
 24.000      90.000
 25.000      90.000
 25.000      85.000

 60.000      95.000
 61.000      95.000
 61.000      90.000

 25.000      85.000
 25.000      90.000
 26.000      90.000

 61.000      90.000
 61.000      95.000
 62.000      95.000
```

THE FOLLOWING POINTS FORM A LEFT PARTIAL REVERSE DOVETAIL

```
 45.000   100.000
 50.000   100.000
 50.000    95.000
```

THE TOOL USED FOR MACHINING THE LEFT PARTIAL REVERSE DOVETAIL
100
NO. OF PASSES REQUIRED 1

THE FOLLOWING POINTS FORM A VERTICALSLOT

```
 20.000   100.000
 20.000    95.000
 30.000    95.000
 30.000   100.000
```

THE TOOL USED FOR MACHINING THE VERTICALSLOT
11
NO. OF PASSES REQUIRED 4

THE FOLLOWING POINTS FORM A RIGHT PARTIAL REVERSE DOVETAIL

```
 72.000    95.000
 72.000   100.000
 77.000   100.000
```

THE TOOL USED FOR MACHINING THE RIGHT PARTIAL REVERSE DOVETAIL
100
NO. OF PASSES REQUIRED 1

THE FOLLOWING POINTS FORM A VERTICALSLOT

```
 50.000   100.000
 50.000    95.000
 72.000    95.000
 72.000   100.000
```

THE TOOL USED FOR MACHINING THE VERTICALSLOT
1
NO. OF PASSES REQUIRED 2

THE FOLLOWING POINTS FORM A TSLOT

```
 20.000    95.000
 14.000    95.000
 14.000    90.000
 36.000    90.000
 36.000    95.000
 30.000    95.000
```

THE TOOL USED FOR MACHINING THE TSLOT 2
NO. OF PASSES REQUIRED 6
ROTATE THE PART 90 DEG. CLOCKWISE

THE FOLLOWING POINTS FORM A REVERSE DOVETAIL

```
  0.000    20.000
  5.000    25.000
  5.000    45.000
  0.000    50.000
```

THE TOOL USED FOR MACHINING THE REVERSE DOVETAIL
100
NO. OF PASSES REQUIRED 3
ROTATE THE PART 90 DEG. CLOCKWISE

THE FOLLOWING POINTS FORM A VERTICALSLOT

```
 50.000     0.000
 50.000    10.000
 40.000    10.000
 40.000     0.000
```

THE TOOL USED FOR MACHINING THE VERTICALSLOT
11
NO. OF PASSES REQUIRED 8
ROTATE THE PART 90 DEG. CLOCKWISE

```
100.000    85.000
 95.000    80.000
 95.000    45.000
100.000    40.000

THE TOOL USED FOR MACHINING THE REVERSE DOVETAIL
100
NO. OF PASSES REQUIRED  5

THE FOLLOWING POINTS FORM A VERTICALSLOT

 95.000    75.000
 90.000    75.000
 90.000    55.000
 95.000    55.000

THE TOOL USED FOR MACHINING THE VERTICALSLOT
  1
NO. OF PASSES REQUIRED  2

THE FOLLOWING POINTS FORM A VERTICALSLOT

 90.000    69.000
 88.000    69.000
 88.000    49.000
 90.000    49.000

THE TOOL USED FOR MACHINING THE VERTICALSLOT
  2
NO. OF PASSES REQUIRED  2
ROTATE THE PART 90 DEG. CLOCKWISE

GIVE THE THICKNESS OF THE PART
50
GIVE THE FEEDRATE
100
GIVE THE SPINDLE SPEED
767

n   2 g 90 x 00000  y 00000  z 00000  f 100 s 767 m 06
n   3 g 00 x 00000  y 00000  z 00000  t   2
n   4 g 90  x  1400 y 00000  z -9500 t   2 f 100 s 767 m 03
n   5 g 90  x  1400 y -5000 z -9500 t   2 f 100 s 767 m 03
n   6 g 90  x  1400 y -5000 z -9500 t   2 f 100 s 767 m 03
n   7 g 90  x  1800 y 00000  z -9500 t   2 f 100 s 767 m 03
n   8 g 90  x  1800 y -5000 z -9500 t   2 f 100 s 767 m 03
n   9 g 90  x  1800 y -5000 z -9500 t   2 f 100 s 767 m 03
n  10 g 90  x  1400 y 00000  z -9500 t   2 f 100 s 767 m 03
n  11 g 90  x  1400 y -5000 z -9300 t   2 f 100 s 767 m 03
n  12 g 90  x  1400 y -5000 z -9300 t   2 f 100 s 767 m 03
n  13 g 90  x  1800 y 00000  z -9500 t   2 f 100 s 767 m 03
n  14 g 90  x  1800 y -5000 z -9300 t   2 f 100 s 767 m 03
n  15 g 90  x  1800 y -5000 z -9300 t   2 f 100 s 767 m 03
n  16 g 90  x  1400 y 00000  z -9500 t   2 f 100 s 767 m 03
n  17 g 90  x  1400 y -5000 z -9200 t   2 f 100 s 767 m 03
n  18 g 90  x  1400 y -5000 z -9200 t   2 f 100 s 767 m 03
n  19 g 90  x  1800 y 00000  z -9500 t   2 f 100 s 767 m 03
n  20 g 90  x  1800 y -5000 z -9200 t   2 f 100 s 767 m 03
n  21 g 90  x  1800 y -5000 z -9200 t   2 f 100 s 767 m 03
n  23 g 90 x 00000  y 00000  z 00000  f 100 s 767 m 06
n  24 g 00 x 00000  y 00000  z 00000  t 100
n  25 g 90  x  1950 y 00000  z    -50 t 100 f 100 s 767 m 03
```

```
n  27 g 90  x  1950 y -5000 z   -50 t 100 f 100 s 767 m 03
n  28 g 90  x  2650 y 00000  z   -50 t 100 f 100 s 767 m 03
n  29 g 90  x  2650 y  5000 z   -50 t 100 f 100 s 767 m 03
n  30 g 90  x  2650 y -5000 z   -50 t 100 f 100 s 767 m 03
n  31 g 90  x  3250 y 00000  z   -50 t 100 f 100 s 767 m 03
n  32 g 90  x  3250 y  5000 z   -50 t 100 f 100 s 767 m 03
n  33 g 90  x  3250 y -5000 z   -50 t 100 f 100 s 767 m 03
n  35 g 90 x 00000  y 00000  z 00000  f 100 s 767 m 06
n  36 g 00 x 00000  y 00000  z 00000  t  11
n  37 g 90  x -5000 y 00000  z     0 t  11 f 100 s 767 m 03
n  38 g 90  x -5000 y  5000 z     0 t  11 f 100 s 767 m 03
n  39 g 90  x -5000 y -5000 z     0 t  11 f 100 s 767 m 03
n  40 g 90  x -4700 y 00000  z     0 t  11 f 100 s 767 m 03
n  41 g 90  x -4700 y  5000 z     0 t  11 f 100 s 767 m 03
n  42 g 90  x -4700 y -5000 z     0 t  11 f 100 s 767 m 03
n  43 g 90  x -4400 y 00000  z     0 t  11 f 100 s 767 m 03
n  44 g 90  x -4400 y  5000 z     0 t  11 f 100 s 767 m 03
n  45 g 90  x -4400 y -5000 z     0 t  11 f 100 s 767 m 03
n  46 g 90  x -4300 y 00000  z     0 t  11 f 100 s 767 m 03
n  47 g 90  x -4300 y  5000 z     0 t  11 f 100 s 767 m 03
n  48 g 90  x -4300 y -5000 z     0 t  11 f 100 s 767 m 03
n  49 g 90  x -5000 y 00000  z     0 t  11 f 100 s 767 m 03
n  50 g 90  x -5000 y  5000 z   500 t  11 f 100 s 767 m 03
n  51 g 90  x -5000 y -5000 z   500 t  11 f 100 s 767 m 03
n  52 g 90  x -4700 y 00000  z     0 t  11 f 100 s 767 m 03
n  53 g 90  x -4700 y  5000 z   500 t  11 f 100 s 767 m 03
n  54 g 90  x -4700 y -5000 z   500 t  11 f 100 s 767 m 03
n  55 g 90  x -4400 y 00000  z     0 t  11 f 100 s 767 m 03
n  56 g 90  x -4400 y  5000 z   500 t  11 f 100 s 767 m 03
n  57 g 90  x -4400 y -5000 z   500 t  11 f 100 s 767 m 03
n  58 g 90  x -4300 y 00000  z     0 t  11 f 100 s 767 m 03
n  59 g 90  x -4300 y  5000 z   500 t  11 f 100 s 767 m 03
n  60 g 90  x -4300 y -5000 z   500 t  11 f 100 s 767 m 03
n  62 g 90 x 00000  y 00000  z 00000  f 100 s 767 m 06
n  63 g 00 x 00000  y 00000  z 00000  t   2
n  64 g 90  x -6900 y 00000  z -9000 t   2 f 100 s 767 m 03
n  65 g 90  x -6900 y  5000 z -9000 t   2 f 100 s 767 m 03
n  66 g 90  x -6900 y -5000 z -9000 t   2 f 100 s 767 m 03
n  67 g 90  x -6700 y 00000  z -9000 t   2 f 100 s 767 m 03
n  68 g 90  x -6700 y  5000 z -9000 t   2 f 100 s 767 m 03
n  69 g 90  x -6700 y -5000 z -9000 t   2 f 100 s 767 m 03

[rkv] exit
script done on Fri Aug 13 09:57:45 1993
```

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